Aircraft Engine Maintenance

by

DANIEL J. BRIMM, Jr., M.A., A.F.I.Ae.S.

Licensed Pilot; Licensed Airplane and Engine Mechanic; Instructor in Airplane Engines, New York City School of Aviation Trades. Formerly Test Pilot; Manager Marine Flying Service; Chief Engineer Ireland Aircraft, Inc.

and

H. EDWARD BOGGESS

Licensed Pilot; Licensed Airplane and Engine Mechanic; Instructor in Airplane Mechanics, New York City School of Aviation Trades. Formerly Ground School Instructor; Flight Mechanic Curtiss Flying Service; Co-pilot Roosevelt Flying Corporation

LONDON
SIR ISAAC PITMAN & SONS, LTD.
1941

SIR ISAAC PITMAN & SONS, LTD.
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, LITTLE COLLINS STREET, MELBOURNE

ASSOCIATED COMPANIES
PITMAN PUBLISHING CORPORATION
2 WEST 45TH STREET, NEW YORK
205 WEST MONROE STREET, CHICAGO
SIR ISAAC PITMAN & SONS (CANADA), LTD.
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381–383 CHURCH STREET, TORONTO

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

In this book, the authors have endeavored to present the fundamentals of engine construction, operation and maintenance in a form which may be readily grasped by a beginner in the field. In addition, there has been included reference material which should be of value to the expert engine mechanic.

There is no intent to supersede or replace the manuals published by the various engine manufacturers. In most cases, instructions are general rather than specific.

Every effort has been made to insure the accuracy and authenticity of all information. In this connection, grateful acknowledgment is made to the various manufacturers of engines and accessories who have cooperated so whole-heartedly in supplying data concerning their products, and whose names will be found where these items are discussed.

DANIEL J. BRIMM, Jr.
H. EDWARD BOGGESS

INTRODUCTION

In order to use this book to the fullest advantage, the reader should understand the system employed in breaking the text into small units.

In addition to the chapter divisions, three types of subdivisions will be found. Most of the chapters are divided into *sections,* which are designated by titles in capital letters in the center of the page. For example, in the chapter on Ignition, the section which deals with magnetos is identified thus:

MAGNETOS

The sections are broken into *sub-sections,* indicated by capital letters on the left margin. An example of a sub-section under magnetos would be:

THE SCINTILLA MAGNETO

The sub-sections are further divided into *topics,* designated by underlined titles at the beginning of the paragraph, in this manner:

Adjusting Breaker Points — By the use of this system of subdivisions the material is separated into small coherent units which make for simplified study and quick and easy reference.

Figure numbers do not run in sequence through the book but begin with "Fig. I" in each *sub-section.* Wherever possible, the illustrations are immediately adjacent to the portion of the text in which they are discussed and in no case are separated from it by more than one page.

It has been the experience of the authors, in giving instruction to hundreds of young men, that the average beginner is greatly in need of training in the nature and use of many fairly common tools. Since the first requirement of a capable mechanic is to handle tools properly, the rather large chapter devoted to this subject is considered well worth while.

Without intent to preach, a few words of caution should be included here. The power plant is probably the most important single unit in the airplane, and the failure of any part of it is likely to have serious, if not fatal, results. It is impossible to give absolutely specific instructions concerning every detail which may fall into the engine mechanic's field of duties. However, three simple rules are sufficient to guide and govern the entire activity of this responsible position, and if strictly observed will result in efficiency, proficiency, and safety:

***First*, be sure that you know how to do a job before you start it.**
***Second*, do each job to the absolute best of your ability.**
***Third*, finish the job before you leave it, unless its condition is obvious.**

TABLE OF CONTENTS

CHAPTER 1
PRELIMINARY CONSIDERATIONS

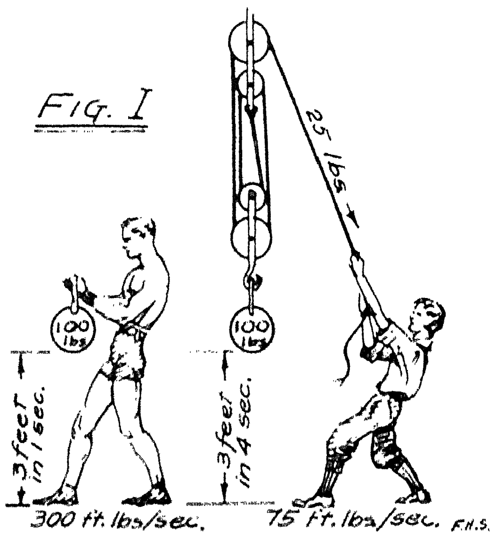
While some of the engineering involved in aircraft engine design is extremely advanced, the rudimentary principles may be readily understood by anyone with a knowledge of simple multiplication and division. It is essential for the individual who desires to become a first-class engine mechanic to be familiar with these principles, which are briefly explained in this chapter. Included also are definitions and explanations of such terms as the student needs to know at this time. The information given below should be read carefully and absorbed thoroughly before proceeding further.

WORK AND POWER

In scientific language, work is the product of a force multiplied by the distance through which the force acts. For example, if a man lifts a weight of 100 pounds to a height of 3 feet, the amount of work done is 300 foot-pounds, since a force of 100 pounds has been exerted through a distance of 3 feet. Thus, in the United States, the unit of work is the foot-pound, usually abbreviated to ft. lb.

A fairly strong man could lift the hundred pounds three feet in one movement. The time required would be, perhaps, one second. On the other hand, a system of pulleys, or what is commonly called a block and tackle, might be arranged so that a small child could also, by pulling on a rope, lift the hundred pounds the distance of three feet and so accomplish the same amount of work, but the time required would be much greater, perhaps four seconds. It is obvious that the man, lifting the weight unaided, exerts much more power than the child. From this it may be readily understood that power involves the time element and is always expressed in work per unit of time. In the case of the child, since the time required for lifting the weight is four times as great, the power is only one-fourth as much, or, 75 ft.lbs./sec.(Fig.I)

FIG. I



The unit of power is the horsepower. This has nothing to do with a horse, though it is probable that the expression was originally determined by the amount of work a horse was considered capable of doing within a specified time. In any case, one horsepower, as used in engineering, is the power required to lift a weight of 33,000 lbs. a height of 1 ft. in 1 minute, or 33,000 ft. lbs./min. If it is desired to express this in terms of seconds, it is obvious that the weight must be reduced to one-sixtieth as much. Hence, a horsepower may also be

defined as 550 ft. lbs./sec., since 550 is one-sixtieth of 33,000. It should be remembered that as long as the product of the weight and the distance is the same, these quantities may be changed at will without affecting the amount of work done, or the amount of power involved. Thus, if 1 lb. were lifted 33,000 ft. in 1 minute, the power exerted would still be 33,000 ft.lbs./min. As a matter of interest, it is estimated that a man can develop only about one-tenth of a horsepower for any appreciable period of time.

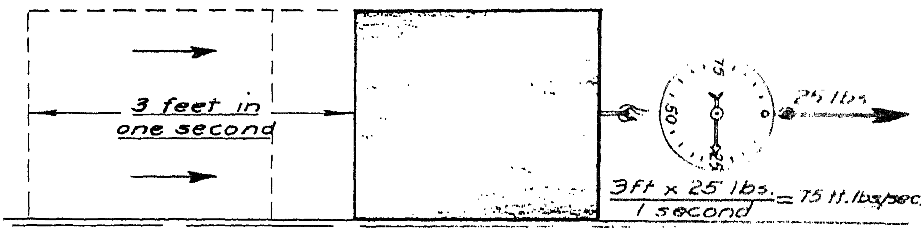


FIG. II

So far we have considered the force as used in lifting a weight. However, force may be exerted in any direction. For example, if a large object is dragged along the ground, the line of action of the force is approximately horizontal. If a spring scale were attached to the object and it were dragged by pulling on the scale, the scale would, of course, register a certain number of pounds. The number of pounds so indicated would be the force required to drag the object. This could be expressed in terms of power by including the time required to move the object a given distance. (Fig. II)

When an airplane is in flight, the air is constantly tending to hold it back. This resistance of the air must be overcome by the engine. For example, if the airplane is moving at 220 ft. per second (which is 150 miles per hour) and the resistance caused by the air is 250 lbs., the power required is, of course, the product of 220 ft./sec. and 250 lbs., or 55,000 ft. lbs./sec. Since 1 horsepower is 550 ft. lbs./sec., it is obvious that the horsepower required to maintain this speed is 55,000 divided by 550, or 100 horsepower.

HEAT ENERGY

Work may be converted into heat and conversely, heat contains energy which is equivalent to a certain amount of work. Since this is the case, heat may be measured not only in heat units but also in units of work. The generally accepted unit of heat is the British thermal unit, abbreviated, b.t.u. One b.t.u. is the quantity of heat required to raise the temperature of 1 lb. of water through 1 degree Fahrenheit. It is equivalent to 778 ft. lbs. of work. The heat energy of a fuel is the quantity of heat that would be developed if a unit weight of the fuel were completely burned with air. Gasoline has greater heat energy per pound than any other common substance, and it is this fact which makes it ideal as a fuel for airplane engines. Combustion, which is simply burning, may be technically defined as the chemical uniting of fuel and oxygen. It is accompanied by the generation of heat. The oxygen is, of course, supplied from the air so that combustion requires both fuel and air, the quantity of air needed being much greater than the quantity of fuel. Under ordinary operating conditions a gasoline engine uses about fifteen

pounds of air to each pound of fuel.

LAWS PERTAINING TO GASES

The two most important laws governing the expansion and compression of gases are known as Boyle's and Charles' Laws respectively. Although these laws do not hold absolutely true with respect to permanent gases, they are sufficiently accurate for practical purposes.

Boyle's Law is that the pressure of a given mass of gas, at constant temperature, varies inversely as the volume. In other words, if the temperature of the gas is not changed, the pressure will increase as the volume is decreased; and the pressure will decrease as the volume is increased.

The word "mass" may be considered as meaning weight, although scientifically there is a distinction between the two. The distinction may be understood by remembering that the weight of a body is simply the force with which the earth attracts it, and is slightly greater at the poles than at the equator, due to the fact that the poles are a little nearer the center of the earth. The mass of the body never varies, whether it is on the equator, at the pole, or out in space.

Charles' Law states that when a gas is allowed to expand under constant pressure, an increase in the temperature will cause a proportionate increase in the volume. It is this principle which causes the gas in the cylinder of an engine to expand when it is heated by its own combustion.

The converse of this law, namely that expansion of a gas is accompanied by a drop in temperature, also holds true. This fact accounts for the decrease in the temperature of the intake manifold of an engine when the fuel vaporizes and expands.

THE AIRPLANE ENGINE

With the foregoing definitions and explanations in mind, we can now define an engine as a device for converting heat energy into mechanical work. In the engines with which we are concerned, this is accomplished by means of a cylinder, a piston, a connecting rod and a crankshaft, as indicated in Fig. III. Pressure in the combustion chamber of the space above the piston moves the piston down. This movement in a straight line is converted into rotary motion by means of the connecting rod and crankshaft. Such engines may have one or a number of cylinders. In the case of the internal combustion engine, which is the only kind used in aircraft, the heat is generated inside of the engine itself - hence the name. An example of the external combustion type is the steam engine, in which the heat is entirely separate from the engine proper and is used simply for the conversion of water to steam.

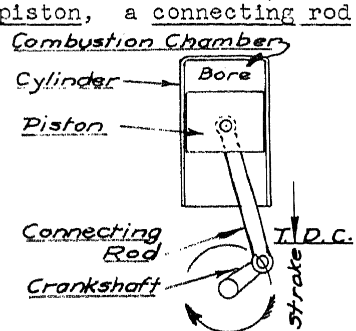


Fig. III

In the steam engine the pressure of the steam against the head of the piston operates the engine. In the case of the internal combus-

tion engine, pressure is produced inside of the cylinder when combustion takes place, for it is a characteristic of gases to expand when they are heated. Since the gas is confined in the cylinder, this expansion causes a pressure on the head of the piston and forces it

The requirements of the airplane engine are more rigid than those of any other type of power plant. It must be light in proportion to its power, since an airplane can carry only so much total weight. Hence, the greater the weight of the engine and the structure, the lower the payload and accordingly the lower the efficiency of the airplane. The airplane engine must be capable of running at or near its maximum power for long periods without undue deterioration. The average automobile engine is seldom run at full power and during most of its operation is called upon for much less than half the power it is capable of producing, since speed limits and traffic conditions obviously prohibit driving a car at its maximum speed. There are no such restrictions on an airplane. The airplane engine must be compact, both to eliminate air resistance and to leave as much space as possible for crew and cargo. It must run smoothly, since vibration is disagreeable and furthermore causes undue abuse of the engine mount and other portions of the power plant. This smoothness must exist both with respect to the evenness of the power impulses and the balance of the moving parts. It is for this reason that the cylinders are arranged to fire in a certain order and the reciprocating parts are counterbalanced. (These matters will be discussed in detail later.) The engine must be flexible, that is, capable of supplying increased power in a minimum of time. It must be easy to maintain and the cost of such maintenance must be kept as low as possible. Likewise the initial cost of the engine must not be excessive. Last, and most important of all, the airplane must be absolutely reliable, for, in a single engine airplane, if the engine stops, a forced landing, with possible disastrous consequences, will result. Even in a multi-engine ship, the failure of one engine results in a tremendous loss of efficiency.

FUELS

Detailed specifications for fuel and oil will be found in a later chapter. Some preliminary knowledge of fuel, however, is necessary to understand the terms and principles to be explained.

While fuels in powdered form have been used for internal combustion engines - in fact, it is believed that the first one was operated on gunpowder - all airplane engines are designed to use liquid fuels, the most common being gasoline and fuel oil, both of which are derived from crude petroleum. The use of fuel oil is at present confined to Diesel engines, which are uncommon in aircraft in the United States but are employed to some extent in Europe. Practically all of the American aircraft engines use gasoline. Considerable thought has been given to alcohol as a fuel for internal combustion engines, chiefly due to the fact that it can be manufactured in unlimited quantities, whereas crude oil, from which gasoline is derived, is a natural product that is gradually being used up. Mixtures of alcohol and gasoline have been used with a fair measure of success. The chief disadvantages of alcohol are: its lower heat energy (about 60% that of gasoline); its weight (15% to 20% more than gasoline); its hygroscopic properties (absorption of moisture from the air); difficulties in starting with engine cold; rust-

ing and wear of cylinders, due to its poor lubricating properties and its moisture content.

One of the specifications of gasoline which should be discussed at this time is the octane rating. For satisfactory operation of a gasoline engine, the combustion should be progressive; in other words, the flame should spread smoothly from the point at which the fuel is ignited throughout the remainder of the charge. If, instead of this smooth spread of flame, a simultaneous explosion of all parts of the charge of fuel occurs, a phenomenon known as detonation or knocking will result. Detonation is difficult to describe, but once heard can be readily recognized. It is frequently referred to as "pinging" because of its metallic clinking sound.

Detonation causes loss of power, over-heating, increase of wear and increase in the fuel required. It may be eliminated by using anti-knock compound, the most common of which is tetra-ethyl lead. Gasoline which has been mixed with this chemical is called ethyl gasoline, and is highly poisonous. The anti-knock properties of a given gasoline are expressed by its octane rating, or octane number. This octane number is determined in an engine specially constructed to measure detonation. The gasoline which is to be tested is first used in the engine and its knocking characteristics under certain conditions of throttle setting and load on the engine determined. The gasoline is then drained from the tank and replaced by a liquid known as heptane, which has very high detonating characteristics. To the heptane is then added iso-octane. Iso-octane has very high anti-detonating properties. The iso-octane is added by degrees until the mixture has the same detonating characteristics, under the same throttle setting and engine load, as the gasoline previously tested. The percentage of the iso-octane in the mixture is then checked. This percentage is the octane number or octane rating of the gasoline. Most of the small airplane engines use gasoline with an octane rating of 73, usually specified as simply "73 octane". The large Pratt & Whitney and Wright engines usually require gasoline with an octane rating above 90. One oil company has developed a 100 octane gasoline. This fuel is, of course, almost completely anti-knock.

FACTORS AFFECTING POWER

There are a fairly large number of factors that affect the power a given engine is capable of producing. A change in any one factor, without a compensating change in some other, or others, will vary the amount of power which it is possible to obtain. A number of these factors are listed below with definitions where necessary, together with some terms not directly pertaining to power but which it is essential to know to understand others.

Bore - The inside diameter of the cylinder. Increasing the bore will increase the amount of fuel and air, or charge, that can be taken into the cylinder and hence will increase the power. See Fig. III.

Top Dead Center, or Top Center - The position of the crankshaft when the piston is at its highest point, or nearest to the head of the cylinder. Abbreviated T.D.C. See Fig. III.

<u>Bottom Dead Center, or Bottom Center</u> - The position of the crankshaft when the piston is at its lowest point, or furthest from the cylinder head. Abbreviated B.D.C. See Fig. III.

<u>Stroke</u> - The total distance the piston moves in one direction, or the length of its movement from top dead center to bottom dead center (or vice versa). Increasing the stroke will increase the amount of charge that can be taken in and thus will increase the power, although there is a limit past which the stroke should not be increased. See Fig. III.

<u>Compression Ratio</u> - The ratio of the volume inside the cylinder when the piston is at bottom dead center to the volume when the piston is at top dead center. In aircraft engines this ratio is usually about 5 or 6 to 1. Increasing the compression ratio will increase the power up to a certain point. However, the higher the compression ratio the greater the likelihood of detonation, and hence the higher must be the octane rating of the fuel.

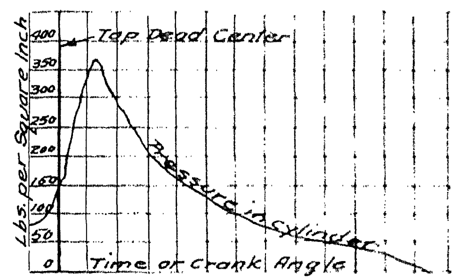


FIG IV

<u>Mean Effective Pressure</u> - The <u>average</u> pressure in pounds per square inch inside of the cylinder during the power stroke. It is usually abbreviated to m.e.p. The m.e.p. is determined to a large extent, naturally, by the compression ratio. The <u>power stroke</u> is the movement of the piston from top center to bottom center caused by the combustion and consequent expansion of the charge. Increasing the m.e.p. will increase the horsepower. The m.e.p. can be measured by a pressure gage or indicator installed in the cylinder. The pressure in the cylinder varies from a maximum shortly after combustion occurs to a minimum near the bottom of the stroke. A chart which shows this variation of pressure is called an indicator diagram. Fig. IV shows such a chart.

<u>R.p.m.</u> - An abbreviation of "revolutions per minute". It is given in this abbreviated form because it is always so written. It means the number of revolutions the crankshaft makes in one minute.

<u>Combustion Chamber</u> - The empty space in the cylinder above the piston. The shape of the combustion chamber has a pronounced effect upon the horsepower since the spread of the combustion or the "flame propagation" is determined to a large extent by this shape. See Fig. III.

<u>Thermal Efficiency</u> - The ratio of the useful work done by an engine to the heat energy in the fuel, when both are expressed in the same units, of either work or heat. It is obvious that if two engines each use the same amount of fuel but one produces more horsepower than the other, the efficiency of the first is greater than that of the second. Thus the power of the engine is, to a large extent, an indication of its thermal efficiency. In addition, high thermal efficiency means that there is less waste heat to dispose of by some method of cooling and also that a lower weight of fuel will

be required for a given flight. Thermal efficiency is affected by many of the factors previously mentioned, such as the compression ratio and the shape of the combustion chamber, and also by such items as adequate lubrication and general mechanical efficiency. The thermal efficiency of the average airplane engine is about 25% at full throttle. In other words, it converts about 25% of the heat energy contained in the fuel into useful work. At slightly less than full throttle, or at what is commonly referred to as cruising r.p.m., this efficiency may be increased in some cases to as much as 35%

Air Temperature, Barometric Pressure and Humidity - By air temperature is meant simply the temperature of the air which is being drawn into the engine to support combustion. The standard temperature for engine testing is 60° F. The barometric pressure indicates the density of the air. Naturally, the less dense the air, and hence the lower the barometric pressure, the lower will be the horsepower produced by the engine. The standard barometric pressure for testing is 29.92 inches of mercury. The humidity, or moisture content of the air, also affects engine performance. The humidity is indicated by the water-vapor pressure and for test conditions should be .4 inches of mercury. An increase in the humidity decreases the power which the engine delivers, since the water vapor in the cylinder produces the amount of oxygen in the air and thus reduces the amount of fuel which can be efficiently burned.

Friction - Friction, or the sliding of one part on another, such as the piston sliding against the cylinder walls, reduces the effective power of the engine, since a certain amount of the power developed is used in overcoming this friction. Friction may be kept to a minimum by properly designed bearings and adequate lubrication.

Unburned Fuel - The losses due to unburned fuel may be reduced by designing the carburetor or fuel injection system so that, as nearly as possible, only such an amount of fuel as can be burned is admitted to the cylinder, particularly at cruising speed. Practically all engines use an excess amount of fuel at full throttle and hence show a high fuel consumption per horsepower under this condition.

DETERMINATION OF EFFECTIVE HORSEPOWER

When the word "horsepower" is used in reference to an aircraft engine, it is usually understood to mean the actual power delivered to the propeller, or the "propeller h.p.". However, there are several sub-divisions which should be understood.

Indicated Horsepower - The power determined from the indicator diagram previously discussed. This is calculated by the following formula:

$$\text{H.P.} = \frac{A \times \text{m.e.p.} \times (S/12) \times \text{ r.p.m.}) \times N}{33{,}000}$$

Where

A = Area of piston head (or cross-section of cylinder) in sq.in.
m.e.p. = Mean effective pressure in lbs./sq.in.
S = Stroke, in inches
r.p.m. = Revolutions per minute
N = Number of cylinders

By referring to the previous explanations of work and power, this formula should be readily understood. The area of the piston times the pressure per sq. in. gives the force on the piston in pounds. The stroke in inches divided by 12 gives the distance in feet the piston travels in one stroke. Since only every other down-stroke is a power stroke, half the r.p.m. gives the number of power strokes or explosions per minute. By multiplying the force in pounds by the distance travelled in feet, we obtain the foot-pounds, and by multiplying the foot-pounds in one stroke by the number of strokes per minute, we get the foot-pounds per minute for one cylinder. Multiplying this by the number of cylinders gives the foot-pounds per minute for the whole engine. And since one horsepower is 33,000 foot-pounds per minute, the numerator is divided by 33,000 to find how many horsepower are being produced. This formula shows the effect on the horsepower of the bore (since the cross-sectional area of the cylinder is $\frac{\pi}{4} \times B^2$), of the stroke, the m.e.p., and the r.p.m., as mentioned in "Factors Affecting Power."

Friction Horsepower - The horsepower used up in overcoming friction, in sucking in the charge and in expelling the burned gases. The power required to drive the oil and fuel pumps, the magnetos, and other accessories is also considered as falling under this head.

Brake Horsepower - The actual horsepower delivered to the propeller, measured by means of a brake or dynamometer of some type. The Prony brake is perhaps the most easily understood device for determining the brake horsepower. A diagram of the Prony brake is shown in Fig. V. Its principle is as follows: The engine is equipped with a flywheel, or brake drum and brake which can be tightened at the will of the operator and which is provided with adequate means of cooling. To the brake is rigidly attached a torque arm. The end of the torque arm is usually connected to a scale, though the same effect may be produced by hanging a weight on the arm and since the latter method is more easily explained it is shown in the diagram. When the engine is turning at the desired r.p.m. the brake is tightened and the force on the scale, or the weight required to hold the arm stationary, is noted. The brake horsepower may then be determined from the following formula:

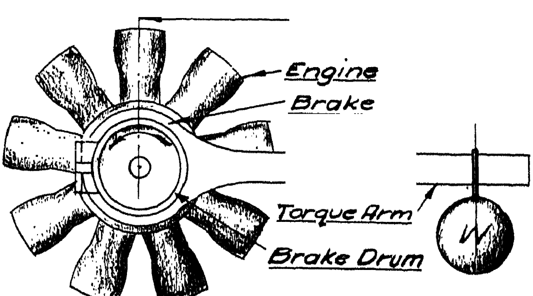


FIG. V

(2) $B.H.P. = 2\pi LNW/33,000$

Where

= 3.1416

L = Length of arm in feet

N = Number of revolutions per minute

W = Weight, or force, in pounds determined by the reading on the scale.

Obviously, the brake horsepower is the difference between the

indicated horsepower and the friction horsepower.

The simple form of the Prony brake, illustrated in Fig. V, is obviously a rather clumsy device and one which makes accurate readings of horsepower difficult, if not impossible. In engine-testing laboratories two types of dynamometers are ordinarily used. One of these is quite similar to the Prony brake except that instead of a weight the torque arm is connected to a hydraulic mechanism provided with gages which show the hydraulic pressure put on the system. From this pressure the actual force on the arm may be easily and accurately computed or indicated. The other type of dynamometer is electrical in principle and is similar to an electric dynamo or generator, run by the engine which is being tested. The electrical resistance of the dynamo may be increased by the test engineer. This resistance corresponds to the brake in the dynamometers previously discussed, and its quantity can be measured by electrical instruments. Due to its accuracy and simplicity of operation, the electric dynamometer is preferred, in most cases, to other types.

In engine factories a calibrated club propeller is commonly used on production engines instead of a dynamometer. A club propeller is one which has short wide blades, usually four, set at a high pitch. Having calibrated, or determined by comparison with dynamometer readings, just how much power is required to turn this propeller at various r.p.m., it may then be used instead of a dynamometer to show how much h.p. is being produced by the engine.

Brake Mean Effective Pressure - The brake mean effective pressure is the m.e.p. which, if acting on the piston, would produce the brake horsepower. In other words, if it were used in formula (1), the answer would be the brake horsepower instead of the indicated horsepower. The b.m.e.p. may be calculated by the following formula:

(3) B.m.e.p. = b.h.p. x 33,000/LAE

Where

L = Length of arm in feet
A = Area of the top of piston
E = The number of explosions per minute, (or ½ r.p.m.)

It should be noted that this formula is derived directly from formula (1).

Maximum Power - The greatest power of which the engine is capable.

Rated Power - The power guaranteed by the manufacturer at a given r.p.m. It is usually somewhat less than the maximum power.

Piston Displacement - The total amount of air displaced by all the pistons during one revolution of the crankshaft. This may be easily determined if the bore, stroke, and number of cylinders are known. The displacement in one cylinder is the cross-sectional area of the cylinder multiplied by the length of the stroke, or $.7854\ B^2 \times S$. This product, multiplied by the number of cylinders, is the displacement.

PROPELLER CONSIDERATIONS

An entire chapter is devoted to propellers further on in this book, but there are a few basic facts which should be mentioned at this time, together with a few definitions.

Pitch - The pitch of a propeller is the distance the propeller would move ahead in one revolution if there were no slip; in other words, if it were moving in a semi-solid medium such as butter. Since the air is not solid and since the propeller must pull the airplane through the air against a certain amount of resistance, it moves in one revolution only 75% or 80% of its pitch.

Diameter - The diameter of the propeller is the diameter of the circle described by the tips of the blades when the propeller is rotating about its centerline.

Blade Area - The area of the rear or driving face of the propeller blade.

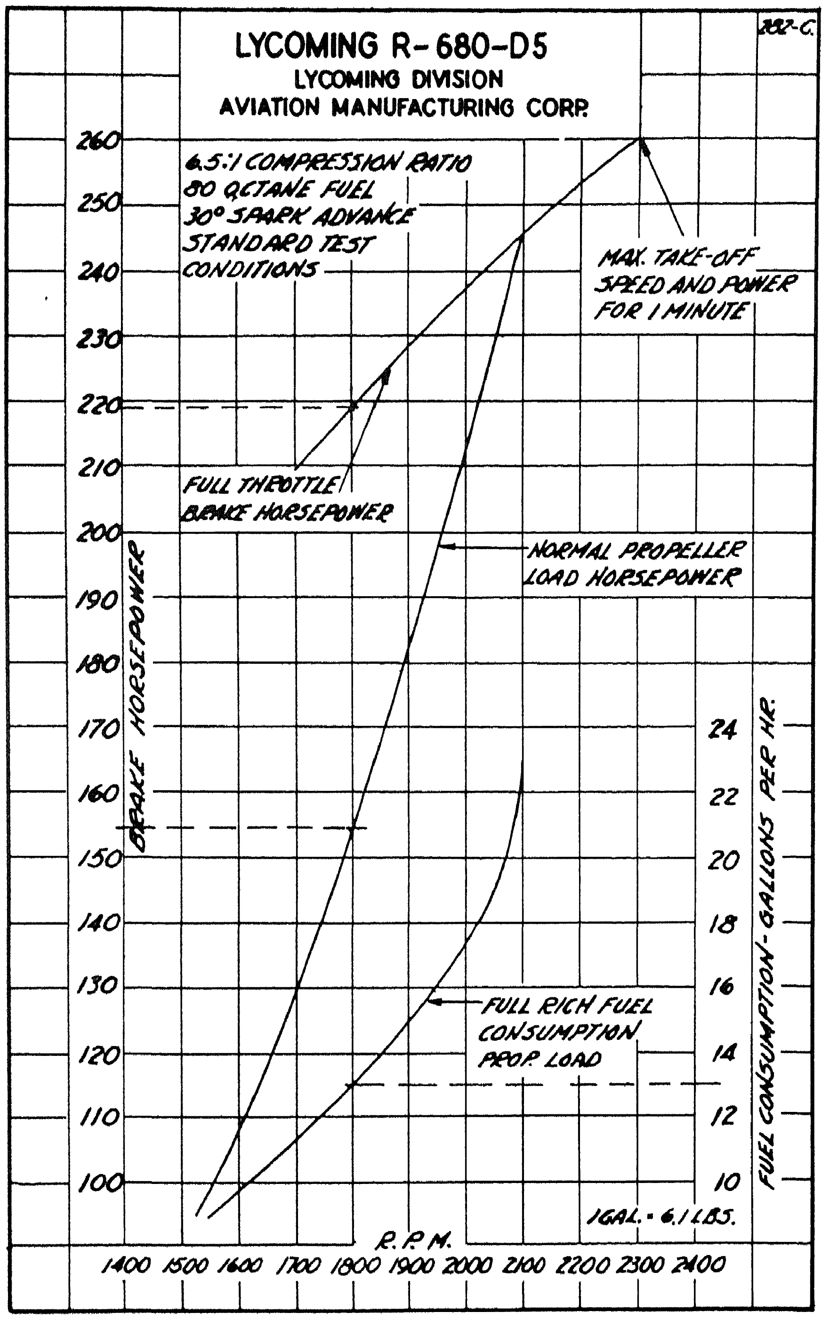
Since the horsepower of an aircraft engine is absorbed entirely by the propeller, it follows that the propeller characteristics control, to a large extent, the behavior of the engine. A given engine will turn a given propeller at a certain r.p.m. in level flight when mounted in a particular airplane. A change in any of these factors will change the others. The same engine and propeller in another ship which has more resistance would not turn as fast. If the pitch of the propeller is decreased, the r.p.m. will increase. If the diameter is increased without changing the pitch, the r.p.m. will decrease. If the blade area of the propeller is increased without changing either the pitch or the diameter, the r.p.m. will decrease. If the ship is put into a climb instead of level flight, the r.p.m. will decrease. These facts should be remembered in studying the flight operation of the engine.

ENGINE PERFORMANCE CHARTS

Fig. VI shows a typical performance chart of an aircraft engine. Such a chart is sometimes called also a horsepower chart or performance curve. Most of the terms used on the one illustrated have been previously explained. However, a brief discussion of the use of the chart is considered desirable.

The engine to which this chart applies is the Lycoming, Model R-680-D5. Immediately below the model number of the engine is stated the compression ratio, defined on page 5. The octane rating of the fuel used in the test is 80. The spark is set to occur 30° before the piston reaches top center. (The reason for this will be explained in a subsequent chapter.) The "standard test conditions" refer to the temperature, the barometric pressure and the humidity, also previously explained, on page 6. On the left side of the chart is found the brake horsepower and at the bottom the revolutions per minute (r.p.m.). There are two horsepower curves, one showing the full throttle brake horsepower, the other the normal propeller load horsepower.

The propeller load h.p. is the power required by the propeller at a given r.p.m. It will be noted that this curve does not extend below 1,500 r.p.m., since the operator of the airplane is not likely to be interested in engine performance at slower speeds.



LYCOMING R-680-D5
LYCOMING DIVISION
AVIATION MANUFACTURING CORP.
282-C.
6.5:1 COMPRESSION RATIO
80 OCTANE FUEL
30° SPARK ADVANCE
STANDARD TEST CONDITIONS
MAX. TAKE-OFF SPEED AND POWER FOR 1 MINUTE
FULL THROTTLE BRAKE HORSEPOWER
NORMAL PROPELLER LOAD HORSEPOWER
FULL RICH FUEL CONSUMPTION PROP. LOAD
BRAKE HORSEPOWER
FUEL CONSUMPTION - GALLONS PER HR.
1 GAL. = 6.1 LBS.
R.P.M.
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
24
22
20
18
16
14
12
10
1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400

To determine the h.p. at, for example, 1,800 r.p.m., the vertical line over the figure "1,800" is followed up until it intersects the horsepower curves. A horizontal line (indicated by dashes, on the illustration) may then be extended from these intersections to the horsepower scale. Following out this procedure, it will be seen that the propeller load h.p. at 1,800 r.p.m. is 154 and the full throttle h.p. is 219. The rated normal brake horsepower is the point at which the propeller load h.p. and the full throttle h.p. meet. In the case of this engine, the intersection occurs at 245 h.p. and 2,100 r.p.m. Accordingly, the engine is said to be rated 245 h.p. at 2,100 r.p.m. It will be noted that the curve of full throttle h.p. is extended to 2,300 r.p.m., at which point the h.p. is 260. It is permissible to use this speed and power for one minute, in taking off. A controllable-pitch propeller is almost essential to make proper use of this added power, since a fixed pitch "prop." which would turn at such a speed on the take-off would be highly inefficient for cruising.

The lowest curve on the chart shows the fuel consumption with the mixture control (to be discussed later) in the full rich position. Many charts give the fuel consumption in lbs./b.h.p.-hr., in other words, the number of pounds of fuel burned in one hour for each horsepower developed. Naturally, in this case, to obtain the hourly consumption the figure given on the fuel consumption scale must be multiplied by the horsepower being produced at the given r.p.m. The chart in Fig. VI gives the fuel consumption in gallons per hour, thus eliminating the calculation just referred to. At 1,800 r.p.m., for example, a horizontal line extended to the scale of fuel consumption shows 13 gallons per hour.

CHAPTER 2
PRINCIPLES AND TYPES

THE FUNCTIONS OF THE GASOLINE ENGINE

The origin of the internal combustion engine is lost in history. It is believed that the Chinese had some sort of device using gunpowder as early as 400 A.D. Such an engine was described by Christian Huyghens in 1680. In 1862 the principles of the four-stroke cycle engine were laid down by Beau de Rochas and were developed by Nicholas A. Otto in 1876. Otto is generally considered as the real father of the internal combustion engine and the four-stroke cycle is often called the Otto cycle. Most airplane engines are of this type, which is explained further in subsequent pages.

As has been previously stated, any internal combustion <u>gasoline</u> engine is simply a mechanical device for converting the energy stored in fuel into power or work. Primarily the power is attained from the rapid expansion caused by the burning of the fuel, or as it

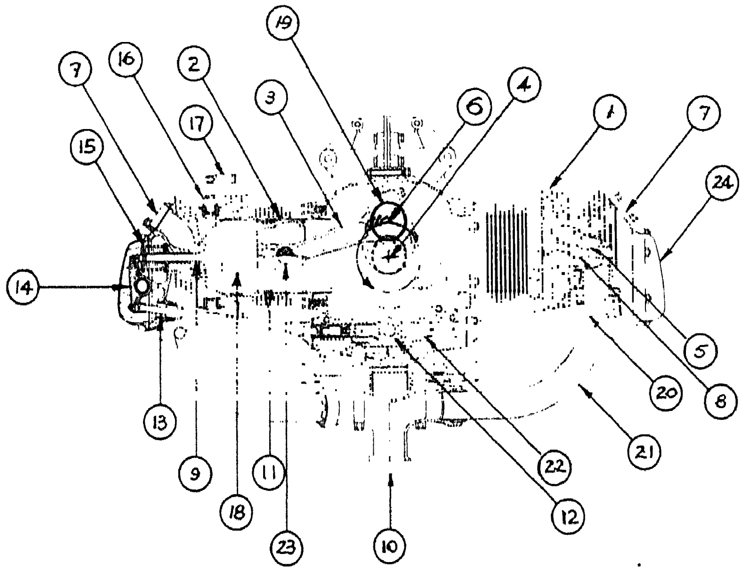


Fig. I
HORIZONTALLY OPPOSED CONTINENTAL A-50

1. Cylinder
2. Piston
3. Connecting rod
4. Crankshaft center
5. Intake port
6. Crankshaft rotation
7. Exhaust port
8. Intake valve
9. Exhaust valve
10. Carburetor intake
11. Piston rings
12. Camshaft
13. Pushrod
14. Rocker arm
15. Valve spring
16. Spark plug
17. Spark plug terminal
18. Combustion chamber
19. Crank pin
20. Pushrod housing
21. Intake pipe
22. Cam follower
23. Piston pin
24. Rocker box cover

is commonly referred to, the explosion. All internal combustion engines must therefore provide some means of supplying the fuel, exploding the fuel, utilizing the energy from the explosions and eliminating the burned gases. Some engines accomplish these operations in one complete revolution of the crankshaft while others require two complete revolutions. The operating principles of these types will be explained after the functions of some of the engine parts have been described.

The engine must have some place in which to confine the explosion and some movable part upon which the explosion may exert its force. This is the purpose of the cylinder, in which the gasoline-air mixture explodes, and the movable piston, which receives the force from the explosion.

The functions of the connecting rod and the crankshaft are basically two-fold: To receive the energy from the piston and to convert it into useful rotary power, and, through its momentum, to return the piston to its position to receive the next explosion, or power impulse. Each movement of the piston from the top of the cylinder to the bottom and from the bottom of the cylinder to the top, is called a stroke. Thus, when the piston is being forced away from the top of the cylinder by the explosion it is said to be on the power stroke. The crankshaft revolves one-half turn, or 180°, for each stroke.

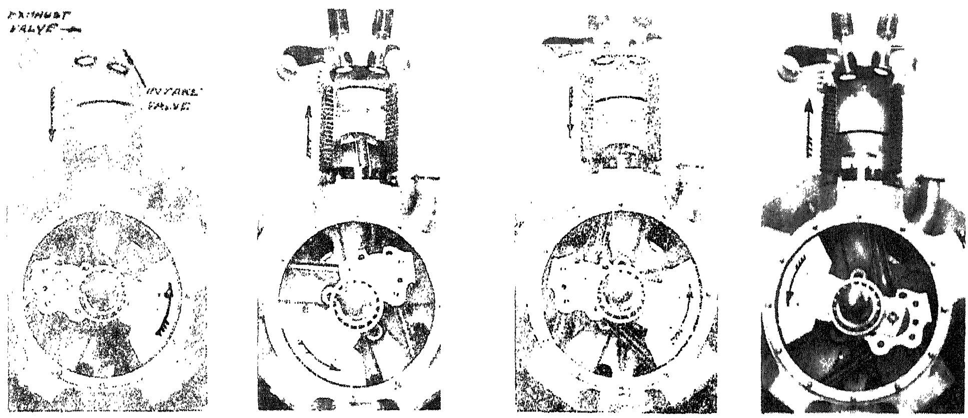
An opening must be provided through which the explosive mixture of fuel may be conducted into the cylinder. This opening is called the intake port. Provision must also be made to allow the burned gases to escape from the cylinder after the explosion. This is accomplished by means of another opening called the exhaust port. These ports must be closed during the explosion, as otherwise practically all the energy of the explosion would be lost. This is done by an intake valve and an exhaust valve, respectively, or by covering the ports with the piston itself.

A mixture of gasoline and air explodes more violently when it is compressed prior to ignition. Proper compression is provided for by introducing the mixture into the cylinder when the piston is at the bottom of its stroke, so that as the piston travels upward it compresses the charge. After being compressed the mixture is ignited by an electric spark at the spark plug.

THE FOUR-STROKE CYCLE ENGINE

The four-stroke cycle engine, commonly called the four cycle engine, requires four strokes of the piston, two down and two up, for a complete cycle. Most aviation engines are of this type. The accompanying illustration shows a Kinner aircraft engine with No. 1 cylinder and part of the crankcase cut away so that the position of the piston, valves, and other parts may be seen during each stroke. The movement or "lift" of the valves has been increased somewhat beyond the normal amount to show the action more clearly.

The rotation of the crankshaft as seen in these illustrations is counterclockwise. The operation is begun, of course, by turning the crankshaft by means of some kind of starter or pulling the pro-



INTAKE STROKE	COMP. STROKE	POWER STROKE	EXHAUST STROKE
Int. Valve Open	Intake Closed	Intake Closed	Intake Closed
Ex.Valve Closed	Exhaust Closed	Exhaust Closed	Exhaust Open

Fig. II

peller by hand until the first explosion takes place, after which the momentum of the moving parts keeps the crankshaft turning until the next explosion and so on.

The first of the four strokes is the intake. The intake valve is opened by a mechanism geared to the crankshaft, as explained later in this chapter. The piston moves downward creating a partial vacuum and sucking in a mixture of gasoline and air from the carburetor through the open intake valve.

On the second, or compression, stroke the intake valve is allowed to close and the mixture is compressed as the piston moves up. Shortly before the piston reaches the top of the stroke, the magneto or battery produces a spark across the points of the spark plug, igniting the compressed mixture. Ignition occurs before top center so as to allow time for combustion. The piston moves on to top center.

The third stroke is the power stroke. The burning mixture expands and forces the piston down. Shortly before the piston reaches bottom center, or the bottom of its stroke, the exhaust valve is opened by the same type of mechanism which operates the intake valve. The last part of the power stroke is the least effective and it is better to open the exhaust valve early and allow more time for the burned mixture to escape than to have the valve remain closed until the piston is all the way down.

The piston moves up for the fourth or exhaust stroke, forcing the burned gas out through the open exhaust valve.

This completes the cycle, which is repeated continuously as long as gas is supplied to the carburetor and the spark occurs in the spark plug. The engine is stopped either by shutting off the gas or by discontinuing the spark.

While only one cylinder is shown in the illustrations, it should be understood that the same series of operations is going on in the others though not exactly at the same time. For instance, in a four-cylinder engine, when one cylinder is on the compression stroke, the next one in the firing order is on the suction or intake stroke.

FUNCTIONS OF ENGINE PARTS

In the four-cycle engine the explosive mixture from the carburetor is drawn into the cylinder through the intake port by the suction created when the piston is on the downward intake stroke. In order to create any appreciable suction, or technically, to lower the pressure in the cylinder, there must be an air-tight seal between the piston and the walls of the cylinder. It would be impractical to fit the piston itself so tightly into the cylinder because of the excessive heat and friction which would be generated. Accordingly, to furnish the required seal, metal rings are fitted into grooves cut in the side walls of the piston. These rings are cut at one point and must be compressed slightly before the piston can be inserted in the cylinder. Once inside the cylinder the rings expand, pressing tightly against the cylinder wall and providing the necessary seal. These rings, usually of cast iron, are called piston rings, or compression rings.

On the intake stroke the intake valve must open automatically to allow the mixture to be drawn into the cylinder. The mechanism that opens the valve is called a valve actuating mechanism, or the valve operating mechanism. This mechanism must be driven by the engine and is therefore geared to the crankshaft. The opening of this valve must be timed, so that it opens at the correct moment - near the beginning of the intake stroke. The most common method of doing this is by means of lobes on a cam gear. The lobes may be on a camshaft on line engines or on a cam ring on radial engines.

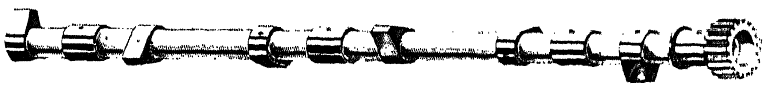


Fig. III

Fig. III shows one type of camshaft. In this illustration it will be seen that the cam has one high spot, or lobe. As the crankshaft turns it drives the cam gear. When the cam gear brings the cam lobe in contact with the lower end of the push rod, the push rod is forced upward, raising the rocker arm which in turn opens the valve. If the valve does not open at the correct time the engine is said to be "out of time." If such is the case the position of the cam gear in relation to the crankshaft must be changed so that the valve does open at the correct time. This procedure is called timing the engine. Further information on timing the engine will be given later.

The gasoline from the tank enters the carburetor through the fuel inlet connection and flows into the float chamber through the needle valve opening. See Fig. IV. From the float chamber the fuel flows through a connecting passage and fills the gasoline outlet standpipe, or jet. As the gasoline fills the float chamber the float rises with the level of the liquid until eventually the float arm

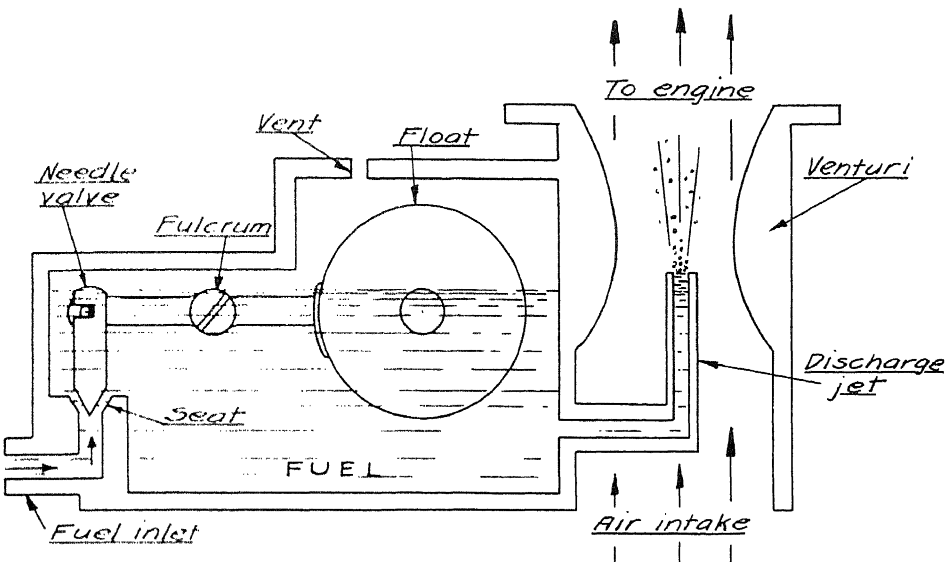


FIG. IV

lowers the needle valve onto the seat, which stops the entrance of gasoline until the level of the gasoline in the float chamber has been lowered by drawing gasoline from the discharge jet. When the gasoline level is lowered, the descending float opens the needle valve passage, admitting more fuel. The float chamber with its automatic gasoline shut-off is necessary, as otherwise the gasoline from the tank would fill the carburetor and overflow from the jet and vent.

The carburetor outlet is connected by a manifold directly to the intake port on the cylinder. When the piston travels downward on the intake stroke the resulting suction draws air into the cylinder through the carburetor air intake. As this rush of air passes the gasoline discharge jet it draws with it a certain amount of gasoline. By regulating the velocity of the air past the jet and the size of the jet itself, the desired ratio of the gasoline-air mixture is obtained. This usually ranges from 14 to 16 parts of air to one part of gasoline.

As the piston nears the bottom of its intake stroke the intake valve must start to close. This is permitted as the pushrod descends on the down-side of the cam lobe. The actual closing of the valve is done by a heavy valve spring. The distance that the valves open, or

the lift, and the length of time they stay open is governed by the height and length, or contour, of the cam lobes.

On the compression stroke the importance of the piston rings is as great or greater than on the suction stroke. Without the rings the mixture would not be fully compressed, but would escape into the crankcase between the piston and the cylinder walls.

During the compression stroke both valves must be closed pressure-tight; otherwise, some of the compressed charge will escape through the valves. For this reason both valves are made with ground faces and are so installed that the compression presses the valve more tightly against its ground seat. If the valves leak, it is necessary to grind them with an abrasive known as valve grinding compound, to renew the surfaces of the valves and the seats.

At the end of the compression stroke the mixture must be ignited. This is done by an electric spark which jumps between the points of a spark plug. The electricity necessary to fire the spark plug is furnished by an ignition system. The firing of the spark plug must be timed to the engine so that the spark will occur at the correct time. On modern aircraft engines the spark plug fires from 25 to 35 degrees of crankshaft rotation before the end of the compression stroke. This is to eliminate the time lag and to insure the full force of the explosion being exerted on the piston at the beginning of its power stroke.

Both valves remain closed through the power stroke as well as through the compression stroke. That is why the cam gear must turn at one-half crankshaft speed, so that each valve will open and close only once for each two revolutions of the crankshaft. Many radial engines have a cam ring which has four lobes for operating each valve. As the valves are actuated only once for each two revolutions of the crankshaft, the cam ring must operate at one-eighth crankshaft speed.

As the piston nears the bottom of the power stroke the exhaust valve must open. On aircraft engines the exhaust valve opens when the throw or offset of the crankshaft is at a point about 50° or 60° before bottom center. In trade language it would be said that the exhaust valve opens 50° to 60° early. The reason for this is that the last part of the stroke is the least effective part and it is better to give as much time as possible for the burned gas to escape. Since the power stroke begins at top center and the power is lost when the exhaust valve opens, and since the length of one stroke is 180° from top center to bottom center, it will be seen that the length of the power impulse is $180^\circ - 50^\circ$ or 130°. Thus, in the five-cylinder engine, there is an interval of $145^\circ - 130^\circ = 15^\circ$ when no power is being applied and the momentum of the moving parts is all that keeps the engine going until the next power impulse. On the other hand, in the twelve-cylinder engine, since there are only 60° between impulses, there is a power overlap of $130^\circ - 60^\circ = 70^\circ$.

This completes the operating cycle of an engine and the running is the constant repetition of these functions, however it must be borne in mind that the one-cylinder engine receives only one power

impulse for every two complete revolutions of the crankshaft and must depend on the momentum of the rotating parts to carry it through the complete cycle. In a large single-cylinder engine the explosions would be so powerful and so far apart that there would be an excessive vibration unless the engine were made exceedingly heavy. This of course would not be satisfactory for an aircraft engine.

By increasing the number of cylinders on an engine more power can be delivered to the crankshaft, as each cylinder fires once for every two revolutions of the crankshaft. Thus, the more cylinders there are, the less the interval between the power impulses. Consequently a smoother engine operation results. Just what the interval is in degrees of rotation may be readily found by dividing 720° by the number of cylinders. The 720°, of course, is the same as two revolutions since one revolution is 360°. Thus, a five-cylinder engine has a gap of 720 divided by 5, or 145° between power impulses and a twelve-cylinder engine has a gap of only 60°.

THE TWO-STROKE CYCLE ENGINE

Internal combustion engines that complete their operating cycle in one revolution of the crankshaft are known as two-stroke cycle engines, or more simply, as two-cycle engines. They are given this name because the piston makes only two strokes for each operating cycle. At present two-cycle engines are rarely, if ever, used for aircraft engines. However, the increasing size and flying range of modern multi-engined transports often present the need for additional power to operate accessories, such as pressure and suction instruments, motor driven equipment, radio, lights, etc. This need is filled by an auxiliary power supply engine which is usually of the two-cycle type. The one-cylinder auxiliary power engine is the most common, although two and four-cylinder engines are sometimes used. Fig. I shows a typical Eclipse auxiliary gasoline engine unit, made especially for use in aircraft.

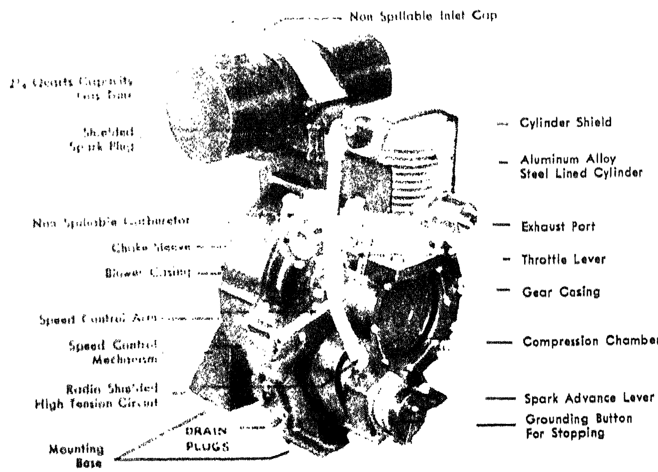


Fig. I
ECLIPSE AUXILIARY POWER ENGINE

The diagrams shown in Figs. II, III, and IV illustrate the three port two- cycle engine. Fig. V shows a two port, two-cycle engine. In Fig. II the piston is on the upward stroke and is performing a double function. By creating a suction, or lowering the pressure in the airtight crankcase, a mixture of fuel from the carburetor is drawn into the crank case through the intake port, when it is uncovered by the

piston. At the same time the piston is compressing the fuel mixture which is in the combustion chamber (from the previous cycle).

In Fig. III the maximum amount of fuel has been drawn into the crankcase and also the combustion chamber mixture has been fully compressed. Near this point the ignition system produces a spark at the spark plug, thereby igniting the compressed charge, the expansion of which causes the piston to start downward on the power stroke. The downward stroke of the piston also serves to compress slightly the mixture in the crankcase. As the piston nears the end of its downward stroke, it uncovers the exhaust port, allowing the burned gases to escape. As the piston continues on its downward stroke the intake port is uncovered, allowing the compressed mixture from the crankcase to escape into the combustion chamber. Since the pressure in the crankcase is greater than the pressure in the cylinder at the time the intake port is uncovered, the exhaust gas cannot force its way into the crankcase. See Fig. IV

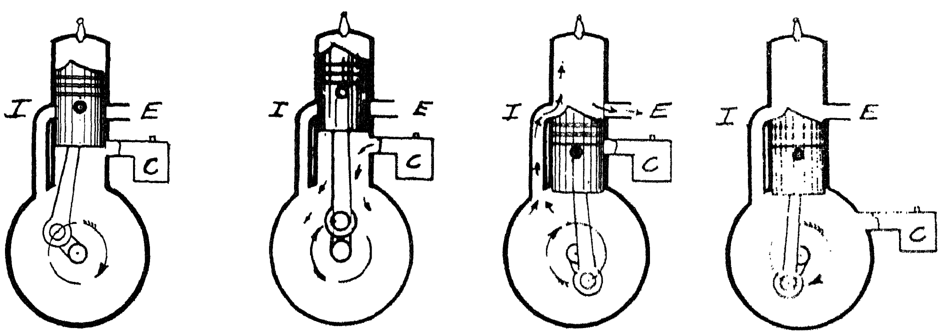


Fig. II Fig. III Fig. IV Fig. V

The charge of gas from the crankcase is prevented from escaping through the exhaust port by a deflector on the head of the piston. The deflector directs the incoming charge toward the top of the cylinder. After the exhaust of the burned gas and the intake of the new charge, the piston starts upward on the next cycle.

The two port engine operates on the same principle as the three port type, with the exception that the carburetor leads directly into the crankcase. A check valve, between the carburetor and the crankcase, allows fuel to be drawn into the engine when the crankcase pressure is lowered, but prevents the mixture from being forced back through the carburetor by the crankcase compression.

The two-cycle engine cannot be lubricated in the conventional manner as the engine heat would convert some of the lubricating oil into oil vapor which would unite with the vaporized fuel. The resulting mixture would not be sufficiently explosive to ignite in the

cylinder. To provide the necessary lubrication, it is common practice to add a small quantity of oil to the gasoline before it is put into the fuel tank, the usual proportion being approximately 1/4 pint of oil to one gallon of gasoline. If no definite gas-oil ratio is specified by the engine manufacturer, it is safe to start with that mentioned and experiment with richer and leaner oil mixtures until the correct proportions for the particular engine have been found. Too much oil in the mixture will cause weak explosions which will be accompanied by considerable white exhaust smoke. Too little oil will cause the engine to become overheated, due to poor lubrication.

Two-cycle engines are often difficult to start. If the engine is in perfect mechanical condition, the fault may lie in an incorrect mixture. An excessive amount of oil in the mixture will cause the spark plugs to become fouled, or short circuited. In this event the plugs should be removed, cleaned in gasoline and dried. On the other hand, if there is not enough oil, the gasoline may wash it from the cylinder walls, thus reducing the compression to such an extent that the engine will not start. A little experience will enable the mechanic to determine when the engine has satisfactory compression. If the compression is low, remove the spark plugs and put a few drops of cylinder oil into each cylinder. Turn the engine by hand through a few revolutions to insure the even distribution of the oil. Then replace the spark plugs and the engine is ready to be started. If it fails to start and all other causes have been eliminated, the trouble may be caused by an accumulation of gasoline and oil in the crankcase. This is best remedied by draining the crankcase.

IN-LINE ENGINES

Engines which have all of their cylinders in one straight line are referred to as in-line engines (see Fig. I). Several of the smaller four and six-cylinder aircraft engines are of this type. In these engines the crankshaft has one throw, or crankshaft offset to which the connecting rod is attached. There is a crankshaft bearing at each end of the crankshaft and also between each two cylinders. Thus, on a four-cylinder in-line engine the crankshaft would have four throws and five main bearings. This makes quite a rugged construction but also rather heavy in comparison with other types. In-line engines of over 6 cylinders have not proved very satisfactory, due largely to the length and consequent weight of the crankshaft. A long crankshaft must be made very heavy to eliminate any "whip" from the power impulses.

The in-line engine uses individual connecting rods with a simple bearing on the crankshaft and the conventional wrist pin bearing. The valves are actuated by the cam lobes on a camshaft which is mounted parallel to the cylinders. The camshaft usually carries both the intake and exhaust cam lobes and is geared to the crankshaft so that it turns at one-half crankshaft speed. Some engines have a separate camshaft for the exhaust and the intake valves. This ordinarily increases the weight and complicates the timing as each camshaft must be timed individually.

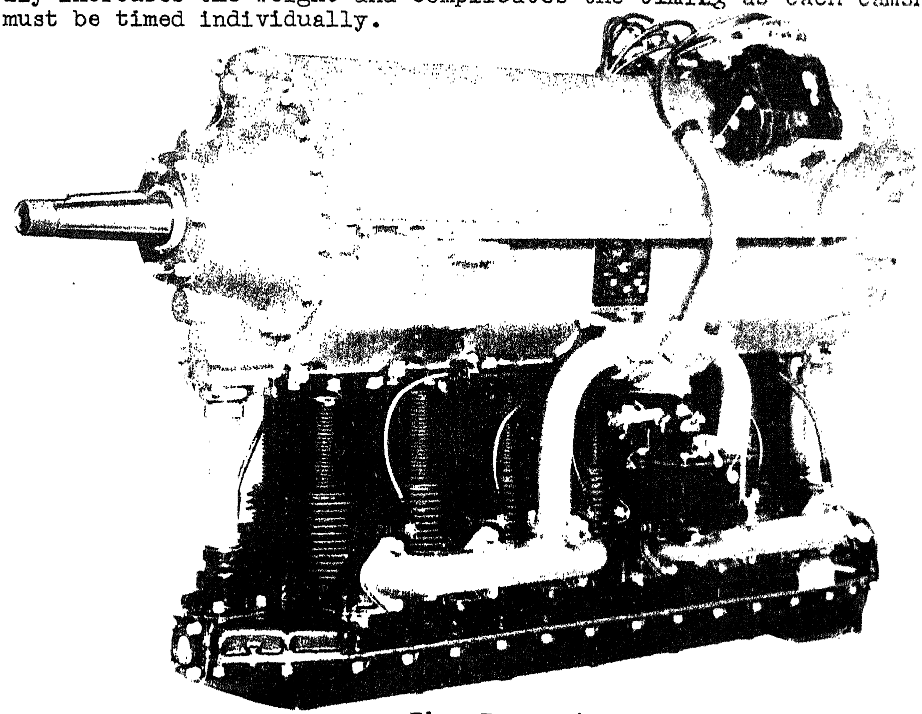


Fig. I

INVERTED RANGER AIRCRAFT ENGINE

If the cylinders are above the crankshaft the engine is called an upright engine, while if they are below the crankshaft it is known as an inverted engine. The inverted engine usually uses the down draft carburetor, which means that the mixture from the carburetor is drawn down into the manifold instead of up, as in the conventional up draft carburetor.

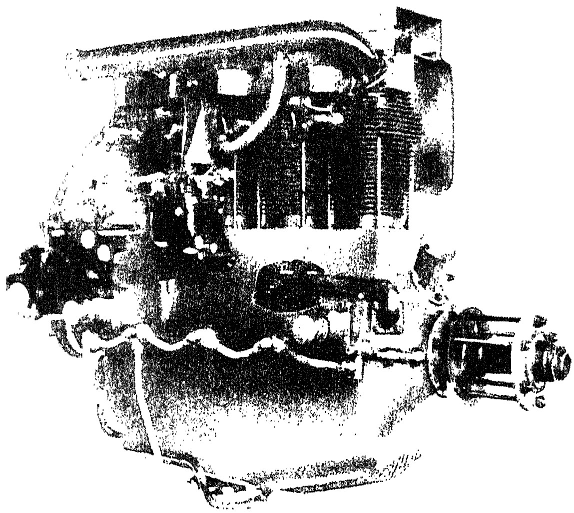


Fig. II - WRIGHT GYPSY ENGINE

The upright engines use either wet sump or dry sump lubrication. The wet sump engine carries the lubricating oil in the crankcase from which it is distributed by a pressure pump to the various parts to be lubricated, and is allowed to drain by gravity back into the sump, or lowest point of the case, where it is again picked up by the pump. The dry sump engine carries the oil in a detached tank from which it is drawn to the engine and pumped to the various parts. The oil then drains to a small sump but is not allowed to accumulate there, being instead returned to the storage tank by a return pump, called scavenger pump. The dry sump system allows a larger quantity of oil to be carried, and also permits better cooling of the oil, as the oil is carried outside of the engine and, if necessary, can be run through an oil-cooling radiator located in the air stream, providing additional cooling. The inverted engines use only the dry sump system, for any large accumulation of oil in the crankcase would run down into the cylinders.

These engines may be either liquid or air cooled. At present, air cooling seems to be more popular. It has been quite a problem, when cooling the engine by air, to get the rear cylinders to run as cool as the front. However, with the use of special air ducts and baffle plates this difficulty has to a large extent been overcome.

In designing all internal combustion engines one of the most important considerations is that of balance. A well balanced engine not only runs more smoothly, but the lack of engine vibration increases the life of engine parts, thereby reducing the cost and trouble associated with constant maintenance. Not only must the rotating parts in an engine be balanced mechanically, but the power impulses also must be balanced, or spaced to provide the smoothest engine operation possible. Engine designers try to space successive

power impulses as far apart on the crankshaft as possible, for if they are closely spaced, the tendency is to cause excessive vibration.

The crankshaft of the four-cylinder in-line engine is balanced by having two throws on one side, and two on the opposite side, as shown in Fig. III. In this crankshaft, throws #1 and #4 (counting from the propeller end) are on top, or at 0° when throws #2 and #3 are on the bottom, or at 180°. Likewise, pistons #1 and #4 are on top center when #2 and #3 are on bottom. The primary forces, or power impulses, are spaced so that when #1 cylinder fires, #4 is on the exhaust stroke. The next half revolution of the crankshaft brings #2 and #3 on top center. One of these cylinders must fire while the other exhausts. The next time #1 and #2 come up, #4 fires and #2 exhausts. On the last half of the second crankshaft revolution #2 and #3 are again on top. The cylinder which was on the exhaust stroke at the previous top center now fires while the other exhausts. From this it may be seen that the firing order of a four-cylinder in-line engine can be either 1, 2, 4, 3, or 1, 3, 4, 2. However, these firing orders are the <u>same</u>, so far as the spacing of the power impulses is concerned.

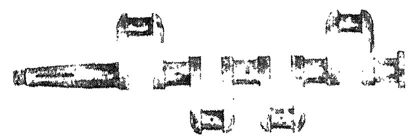


Fig. III

The power impulses are more evenly balanced on the six-cylinder in-line engine than on the four-cylinder. The crankshaft on the six-cylinder engine is arranged so that the throws are spaced in pairs, as shown in Fig. IV. Throws #1 and #6 constitute a pair, as do #2 and #5, and also #3 and #4. There are 120° between each pair of throws. When #1 fires #6 is on the exhaust. The next cylinder to fire is either #5 or #2. #5 is chosen because it is further away, consequently #2 will be on the exhaust. Next, #3 fires and #4 exhausts. On the next complete revolution of the crankshaft the cylinders which were previously on the exhaust stroke fire. The complete firing order is 1, 5, 3, 6, 2, 4.

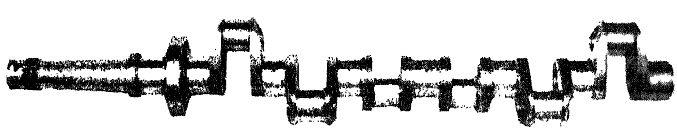
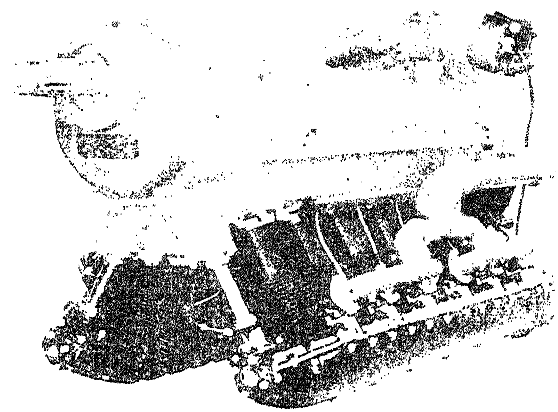


Fig. IV

SIX-CYLINDER CRANKSHAFT

VEE TYPE ENGINES

Engines that have two lines or banks of cylinders at an angle to each other (the angle usually 60° or 90°, though 45° is sometimes used), are called Vee engines. See Fig. I. These are usually the larger engines of eight or twelve cylinders. The Vee type of construction gives a compact engine with even less frontal area than the popular radial design. Vee engines use a crankshaft having one throw for each two cylinders, with the same bearing arrangement as on the in-line engines. Thus, an eight-cylinder Vee engine would have a crankshaft with four throws and five main shaft bearings. A twelve-cylinder Vee engine crankshaft is similar to the six-cylinder in-line crankshaft, with six throws and seven bearings.

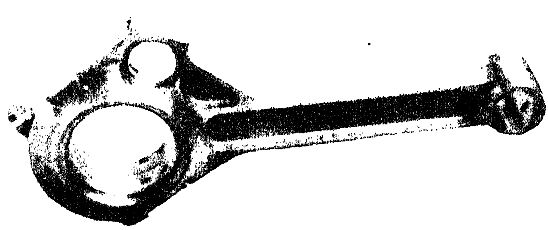


INVERTED VEE RANGER ENGINE

Fig. I

Connecting rods for these engines are either of the yoke or articulating type. In the yoke type, one connecting rod bearing fits onto the crankshaft and the rod to the opposite cylinder fits as a yoke, or fork, on the outside of the first bearing. This necessitates the first, or inside, bearing having a bearing surface on the outside as well as on the inside. This type of bearing may appear to be inefficient, but it has proved quite satisfactory. Fig. II shows a master articulating rod which consists of a large connecting rod bearing on the crankshaft to which the other rod is attached with a knuckle pin.

These engines usually have overhead camshafts. In other words, the camshafts are mounted over the tops of the cylinders in such a manner that the cam lobes can open the valves either by direct contact or through short rocker arms. See Fig. III. The camshafts are geared to the crankshaft through vertical tower shafts and of course turn at one-half engine speed.



CURTISS CONQUEROR MASTER ROD

Fig. II

The upright Vee engines (those whose cylinders are above the crankshaft) usually have the carburetor nestled between the banks, while the exhaust ports are on the outside. The inverted Vee engines (cylinders below

the crankshaft) sometimes have down-draft carburetors to the outsides of the cylinder banks with the exhaust manifolds between the banks. There are many variations of the carburetion and exhaust system on the Vee engines, some having one, two or four carburetors and either short stacks or exhaust manifolds placed between or outside the banks.

The small frontal area in proportion to the horsepower of Vee engines has already been mentioned, but despite this fact they are not as popular as the radial type. This may be due to the earlier Vee engines having been water cooled. Liquid cooling adds to the weight of the engine because of the additional weight of the liquid circulating pump, the cooling radiator and the liquid itself. The "plumbing" necessary for a liquid cooling system not only increases the weight but is an added source of trouble. Unless wing radiators are used the increased resistance presented by the conventional radiator makes the total frontal area of the installation about the same as that of a radial engine. Some of the modern Vee engines, such as the Ranger, are air cooled. These engines not only have a small frontal area but eliminate all the weight and maintenance associated with liquid cooling.

450 H.P. RANGER
Fig. III

The Vee type engines nearly always use the dry sump system for lubrication. The most common exception was the war-time "Hisso", which is no longer in use to any extent.

As a rule, the firing order of these engines is the same as the firing order of the in-line engines. It is divided so that one cylinder on each bank fires alternately and the firing starts on opposite corners, however the firing sequence is the same. The first cylinder to fire (in the firing order of a twelve-cylinder Vee), would be No. 1 on the left bank. The next cylinder to fire would be on the opposite corner, or No. 6 on the right bank. The complete firing order would be 1L - 6R - 5L - 2R - 3L - 4R - 6L - 1R - 2L - 5R - 4L - 3R. This does not apply to some models of the Ranger engines, which fire 1R - 3L - 4R - 5L - 2R - 1L - 6R - 4L - 3R - 2L - 5R - 6L.

HORIZONTALLY OPPOSED ENGINES

Horizontally opposed engines are those engines which have their cylinders in two banks which are opposite, or 180° apart. In other words they are similar to Vee type engines, except there is 180° between the banks instead of the 60° or 90° found in Vee engines. Up to the present the use of the opposed type engines has been almost entirely confined to small two- and four-cylinder engines, of 30 to 50 horsepower, for small sport planes. It is possible that in the future, larger engines of this type will be developed which can be installed inside the wing. Horizontally opposed engines are particularly adapted to this method of installation, as their overall height, even in the higher horsepower range, could be as little as 12 to 18 inches.

The two-cylinder Aeronca engine, and the four-cylinder Continental engine, shown at the beginning of this chapter, are two popular models of the small opposed type. While it is true that these engines present more frontal area than a straight in-line engine, this disadvantage is more than offset by more efficient cooling. Also, at the low top speeds which light planes attain, additional frontal area does not constitute a major factor.

Many of these engines are of the wet sump type, carrying their oil in a finned crankcase which is exposed to the slipstream to provide a certain amount of cooling for the oil. The Aeronca engine has a two-throw crankshaft with offset connecting rods which allow the cylinders to be placed nearly in line, though necessarily one cylinder is slightly behind the other. As both pistons are on top center at the same time, one is on the compression stroke while the other is on the exhaust. Naturally, the firing order is 1, 2.

The Continental engine has a four-throw crankshaft, so constructed that both pistons in one set of opposed cylinders are on top center while the opposide set are on bottom center. The firing order of these engines is 1, 3, 2, 4. These small engines are made as simple and rugged as possible to satisfy the demand for an inexpensive engine for sport planes, in order to keep the weight to a minimum without sacrificing performance or dependability.

"W" AND "X" TYPE ENGINES

Engines that have three banks of cylinders parallel to a common crankshaft are called "W" engines. The "X" engine has four banks of cylinders parallel to the common crankshaft. The purpose of the design is to obtain high horsepower with a relatively small frontal area. In general construction the type is similar to the Vee engines with one or two more banks added. The crankshaft has one throw for each three, or four, cylinders. The connecting rods are of the articulating type, having one large rod bearing with two articulating rods for the W, and three for the X.

These engines are liquid cooled and the air resistance of the cooling radiators is partially or entirely eliminated by the use of wing radiators. At present none of these engines are used in production ships, therefore their discussion is not within the scope of this book.

ROTARY ENGINES

One of the earliest successful types of aircraft engines was the rotary radial. In a radial engine the cylinders are arranged like the spokes of a wheel. The unique feature of the rotary radial is the fact that the crankshaft remains stationary while the cylinders and crankcase revolve around it, the crankshaft being rigidly attached to the fuselage while the propeller is bolted to an extension of the crankcase. Since these engines were air-cooled, it was believed that by having the cylinders rotate in this manner better cooling would be obtained.

The only two rotary engines which achieved any great prominence were the Gnome and the Le Rhone. The Gnome was the first developed and was used widely in training and military airplanes during the early part of the World War. It was later replaced by the Le Rhone, but both engines have been obsolete for many years, though in appearance they did not differ greatly from the modern types. The Gnome was built in various sizes with seven, nine, and fourteen cylinders, the fourteen cylinder model producing about 180 horsepower.

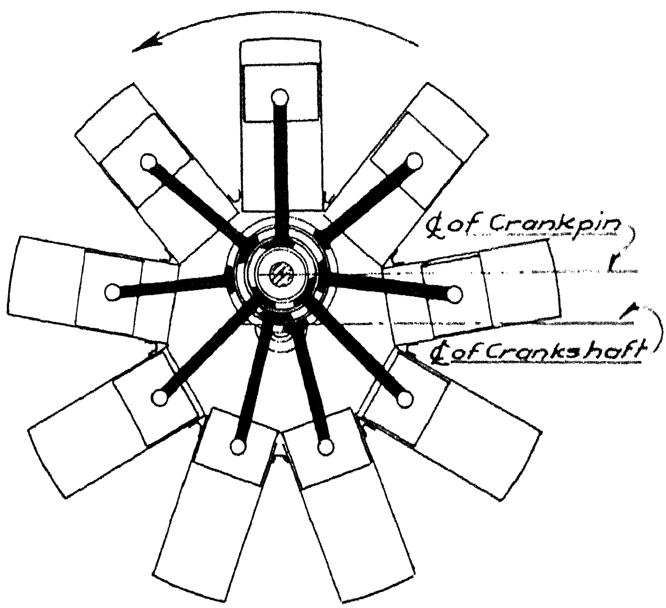


Fig. I

A diagram of the cylinder, connecting rod and crankshaft arrangement of the Le Rhone is shown in Fig. I. The Gnome arrangement is quite similar except for the manner in which the connecting rod is attached to the crankpin. In the Le Rhone, the ends of the connecting rods are provided with "feet" which are clamped between grooved disks. The connecting rods and "feet" are shown in solid black in Fig. I with one of the grooved disks removed. This arrangement permits quick disassembly and appears to have been satisfactory although no such construction is used in modern engines.

In the Gnome the "master" connecting rod, leading to No. 1 cylinder, was made with a large bearing on the crankshaft end. To this bearing the other rods, or link rods, were connected by means of knuckle pins. This type of construction is used in all modern radial engines, even though the cylinders of the modern type do not rotate.

Obviously, with the cylinders rotating, the matter of introducing fuel to them presented certain problems. These were overcome by leading the fuel through a hollow crankshaft into the crankcase. In the earlier types of Gnome engine the carburetor consisted of nothing but a spray nozzle, past which the air flowed on its way to the crankcase. The mixture of fuel and air was allowed to pass into the combustion chamber through an intake valve in the head of the piston. This valve opened as the piston moved down and closed as it moved up. The burned fuel was discharged through an exhaust valve in the top of the cylinder, as in modern engines. Later types of the Gnome eliminated the valve in the head of the piston and led the gas into the cylinder through holes, or ports, drilled in the cylinder skirt below the point where the cylinder entered the crankcase. These ports were uncovered by the piston at the bottom of the stroke very much as in a modern two-cycle engine, although the Gnome was a four-cycle type. In this later model the exhaust valve was also in the head of the cylinder, but since there was no intake valve, the model was frequently referred to as the "Monosoupape", or single-valve. These engines could not be throttled and ran either at full speed or not at all. The only control that the pilot had over the engine was through the ignition, which was cut off, in most airplanes, by means of a button on top of the control stick called the "coupe" button. The ignition remained "On" except when this button was pressed. When the pilot wished to cut off the engine to glide in for a landing, he did so by pressing this button, releasing it intermittently and turning the engine on again, so as to keep it warm and ready for use. The same practice was followed in taxiing. In the Le Rhone, the gas was brought through the hollow crankshaft into the crankcase, but from there was led to the combustion chamber by induction pipes. One of the novel features of the Le Rhone was the method of operating both the intake and exhaust valves by the same push rod. This was done through the use of a cleverly designed cam ring. The Le Rhone had no throttle such as those used by modern engines, but the amount of fuel supplied could be controlled to a certain extent, and the speed of the engine regulated in this manner.

One other rotary engine was fairly common during the War. This was the Clerget, which might be considered a combination of the Gnome and Le Rhone types. The intake and exhaust valves were located in the cylinder heads, but were operated by separate push rods. The master rod assembly was similar to that used in the Gnome. The fuel was taken into the crankcase through a hollow crankshaft, as in the case of the other two engines, and from there was led through induction pipes to the inlet port in the top of the cylinder. The amount of fuel was regulated by a needle valve, very much like the device used on the Le Rhone.

SINGLE-ROW RADIAL ENGINES

Static radial engines, those in which the cylinders do not rotate, may be divided into two main classifications: the single-row, and the twin-row. In the single row type, an example of which is shown in Fig. I, the cylinders are spaced evenly, in one plane around the crankshaft. All the connecting rods lead to their respective pistons from one large bearing on a single-throw crankshaft.

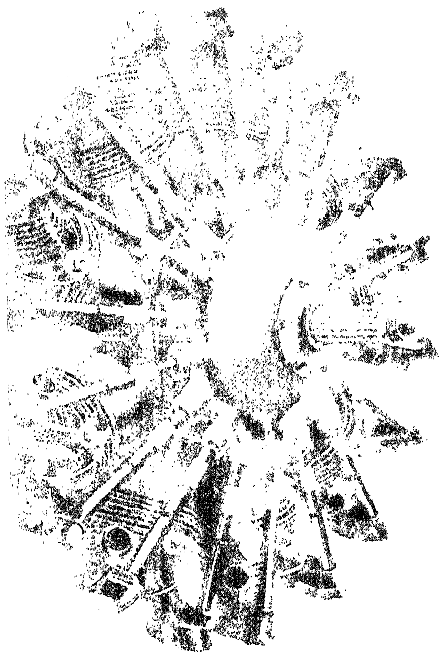


Fig. I
LYCOMING AVIATION ENGINE

Single-row radial engines have an odd number of cylinders usually three, five, seven or nine. They are made in this manner in order to secure a combination of power impulses that will be spaced evenly throughout the entire 720° of the operating cycle. For example, a six-cylinder single-row radial could have a firing order of 1, 2, 3, 4, 5, 6, as each piston comes to top center in rotation. However, in this event, all of the cylinders would fire in one revolution of the crankshaft and the engine would have to "coast" through the next revolution to allow each cylinder to exhaust. Or, it would be mechanically possible to have the explosions spaced 1, 3, 5, 6, 2, 4, but this would mean that two cylinders, 5 and 6, would fire consecutively, and then there would be a large gap between #4 and #1. In either case the engine would be exceedingly rough.

With an odd number of cylinders the power impulses are spaced so that there is a gap of one cylinder between each explosion. Thus on a nine-cylinder engine, the cylinders to fire on the first revolution of the crankshaft are 1, 3, 5, 7 and 9. Meanwhile, the even numbered cylinders are exhausting. On the second crankshaft revolution cylinders 2, 4, 6 and 8 fire and the others exhaust. Thus, it may be said that the firing order of single-row radial engines is every other one, or 1, 3, 5, 2, 4 for a five-cylinder; 1, 3, 5, 7, 2, 4, 6 for a seven, and 1, 3, 5, 7, 9, 2, 4, 6, 8 for a nine. Of course it would be possible to fire the cylinders in rotation but as previously mentioned, this would necessitate the engine coasting for one crankshaft revolution.

The crankshaft, having only one throw, can consequently be made quite strong without being as heavy as those on in-line engines. The crankshaft main bearings are on each side of the throw and are usu-

ally of the ball or roller bearing type. The connecting rods are of the articulating type, similar to those used on the W and X engines. The master, or "mother" rod has a large crankshaft bearing and all other rods are pinned to this bearing with knuckle pins. See Fig. II

The overhead valves are opened by a rocker arm and push rod assembly which in turn is actuated by the cam lobes on a cam ring geared to the crankshaft. The cam ring, having four lobes (in most cases) naturally turns only one-eighth of crankshaft speed, since each valve is actuated four times for each cam ring revolution which allows for eight crankshaft revolutions.

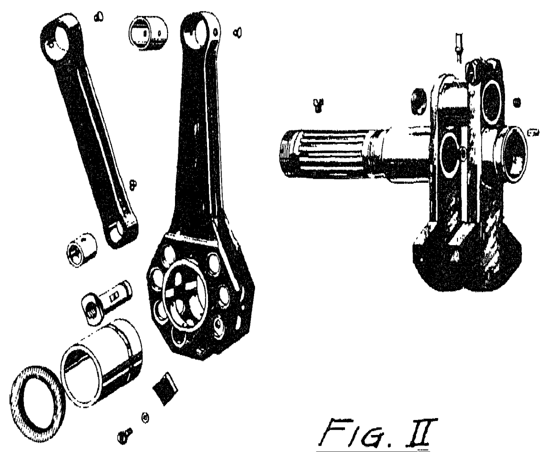


FIG. II

Courtesy WRIGHT AERONAUTICAL

Radial engines are usually air cooled, saving considerable weight, due to the elimination of water radiators, tanks, plumbing, etc., as well as avoiding all trouble with liquid cooling systems. These engines present a larger frontal area than in-line and Vee engines of equal horsepower, but this objection is partially offset by their compactness and lower weight.

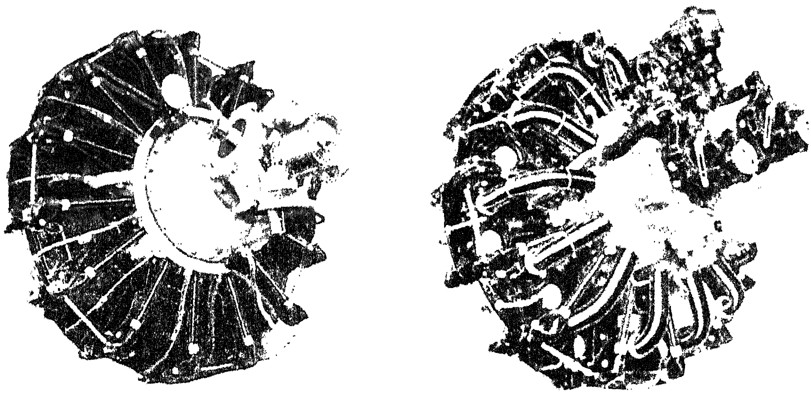
The carburetor delivers the fuel mixture directly into a section of the crankcase, where it is diffused and distributed through individual pipes to each cylinder. There are many types of crankcase diffusers and blowers which will be described later.

Although some radial engine installations still employ short exhaust stacks from each cylinder, in most cases the cylinders exhaust into a common collector ring. From the collector ring, one or two outlets can be lead to some suitable place for exhausting the gas. See Exhaust Systems.

TWIN-ROW RADIAL ENGINES

The twin-row radial engine has been developed to meet the demand for a powerful air cooled radial engine with small frontal area. The 14 cylinder twin-row radial, the most popular type at present, consists of two rows of 7 cylinders each, mounted on one elongated crankcase. The crankshaft has two throws, one for each row of cylinders.

The rear cylinders are located directly behind the openings between the front cylinders, to provide better cooling of the second row. Each cylinder is equipped with an air baffle, which assures pressure cooling and also serves to keep the hot air from the front cylinders away from those in the rear. These baffles are discussed more fully in Chapter III.



Three-quarters front and three-quarters rear views of Pratt & Whitney 14 cylinder Twin-Row Wasp Engine

Fig. I

The valves are actuated by two separate cam rings, therefore each row of cylinders must be timed independently. These engines are usually equipped with force feed lubrication to the overhead valve mechanism.

The two throws on a twin-row radial crankshaft are 180° apart. This means that when one piston in the front row is on top center, the opposite piston on the rear row will also be on top center. As two cylinders do not fire simultaneously, one of the two mentioned is on the exhaust stroke, while the other is on the compression stroke. The cylinders are numbered consecutively in direction of rotation, thus #1 will be the vertical cylinder on the rear row, #2 will be on the front row, #3 on the rear row, etc. The complete firing order for these engines is 1, 10, 5, 14, 9, 4, 13, 8, 3, 12, 7, 2, 11, 6. At first glance this may seem to be a rather complicated firing order, however, each row fires every other cylinder, exactly as a single-row radial. So, starting with #1 in the rear row the order in which the cylinders in this row would fire would be 1, 5, 9, 13, 3, 7, 11. The first cylinder to fire after #1, is #10 on the

front row. Starting with #10 on the front row, the firing order of that row would be 10, 14, 4, 8, 12, 2, 6. Now by combining the two firing orders so that the firing alternates between the front and back rows, the complete firing order will result. The diagram below may be of some help in tracing the firing order.

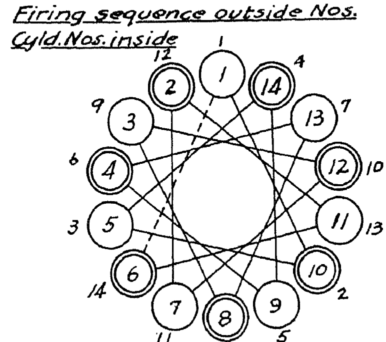
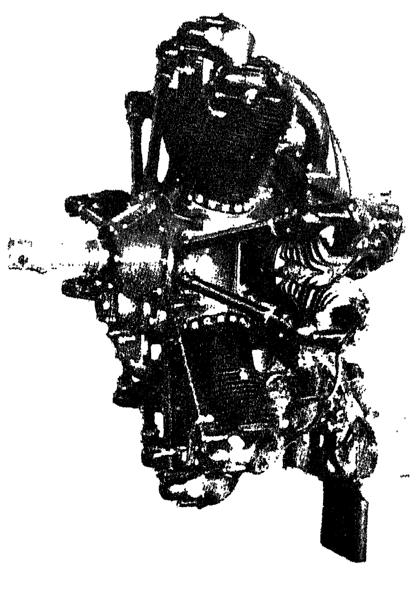


FIG II

Two of the earlier types of engines which may be classed as twin-row radials are the Curtiss Chieftain and the Curtiss Challenger. The former was a twelve-cylinder air cooled engine in which the rear cylinders were placed directly behind those in the front row.

The Curtiss Challenger was an air cooled six-cylinder engine having a staggered cylinder arrangement as shown in Fig. III. Engines of this type were used extensively on many types of small planes. The world's refueling endurance record was broken several times by ships powered with Curtiss Challenger engines.



CHALLENGER ENGINE, showing staggered arrangement of cylinders

Fig. III

DIESEL ENGINES

The Diesel engine, named after its inventor, Rudolph Diesel, is not used in American aircraft at present. However this type is found in some foreign ships, and for that reason a mechanic should have some knowledge of its operations and principles.

The major differences between the Diesel and the gasoline engine lie in the type of fuel used, the charging of the cylinder and the method of igniting the charge. Diesel engines may employ either the two- or four-stroke cycle.

The fuel used in the Diesel engine is called distillate, or fuel oil. This is a petroleum derivative similar to furnace oil. Fuel oil is more easily obtained than is gasoline in some foreign countries, which may account for the popularity of the Diesel engine in these countries.

DIESEL OPERATION

The first stroke of the operating cycle, the suction stroke, draws a charge of air into the cylinder, as in Fig. I-A. The second, or compression stroke, compresses the air in the cylinder approximately 14 to 16 times its original volume. This raises the temperature of the air to about 1200° F. (The temperature of a gas rises when it is compressed.)

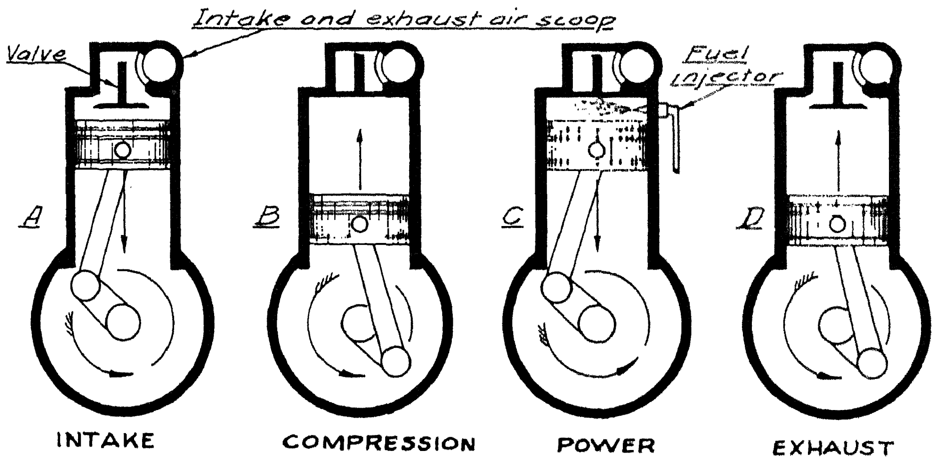


FIG. I

When the piston reaches a point near the end of its compression stroke, fuel is injected into the cylinder from a fuel injector pump as shown in Fig. I-C. The fuel ignites as soon as it comes in contact with the super-heated air. This combustion forces the piston down on the power stroke.

Near the bottom of the power stroke the single valve opens and the exhaust gases are forced out on the exhaust stroke of the piston. See Fig. I-D. The exhaust gases escape through the open port into a cylindrical scoop which is open at both ends. The air stream from the propeller blows through this scoop, quickly clearing it of

burned gases. The single valve remains open, providing the air intake for the next cycle.

Of course all Diesels do not operate exactly on this principle. Some have a separate valve for both intake and exhaust, and some are two-cycle engines. Some, as the Junkers Jumo, have two pistons in each cylinder. These engines have two crankshafts, one at each end of the cylinder barrel, so arranged that the pistons compress the air in the middle of the cylinder barrel. The explosion in this case acts on both pistons, forcing them outward. Each crankshaft is geared to a stub shaft to which the propeller is attached.

Control - The engine speed is controlled by a throttle which is attached to the fuel injection pumps. Movement of the throttle increases or decreases the amount of fuel injected by the pump. Diesel engines are stopped by pulling the throttle past the idling speed stop. This cuts off the fuel supply to the injection pumps or stops the pumps from functioning. In either case no fuel can be delivered to the cylinders, therefore the engine stops.

In starting the engine, the throttle is placed slightly ahead of the idling speed stop and the crankshaft turned by a heavy duty conventional type electric starter. For cold weather starting the cylinders are equipped with glow plugs. These are simply continuous operating heating elements, somewhat similar to electric cigar lighters, and serve to increase the temperature of the air inside the cylinder.

DIESEL CONSTRUCTION

Diesel engines may be either air or liquid cooled. However, due to the greater heat generated by these engines the liquid cooling has proved to be the more practical. Some experiments have been made using steam for cooling. By utilizing steam for the cooling agent it is claimed that a higher efficiency is obtained, due to the fact that the engine operating temperature can be controlled within the range of 300° to 400° F. This means that less of the heat-energy has to be dissipated.

The high compression of Diesels creates more problems than just that of cooling. The cylinders and pistons must be stronger than those of gasoline engines. The cylinder anchorage and crankcase must be stronger. The conventional cast iron piston rings are replaced by cast steel rings. This increases the possibility of the piston rings "seizing", or welding to the cylinder wall, as the two materials are nearer the same hardness.

The fuel injection system usually consists of an injection head protruding into the cylinder and attached to a small high pressure fuel pump. The fuel is subjected to tremendous pressure in the pump and is released, at the correct time, into the injector either from individual cam mechanisms or from a central distributor. After the fuel reaches the injector it is sprayed into the cylinder through an extremely fine nozzle. The nozzle discharge opening is sometimes as small as .004" in diameter. The discharge nozzles sometimes cause trouble because the small hole occasionally becomes plugged with carbon. However, if sufficient pressure is exerted on the fuel as it enters the nozzle, very little real difficulty is encountered.

CHAPTER 3

CONSTRUCTION AND DETAILS

ENGINE DETAILS

While it is not necessary for the mechanic to know the construction methods used in the fabrication of various aircraft engine parts and the metallurgical composition of the materials from which they are made, it is desirable that he have some idea of the types of construction and kinds of metals used. No attempt will be made here to describe the manufacturing operations for they are changing so rapidly that a process which is popular today may be obsolete tomorrow. The aircraft engine plant seldom has a great amount of mass production machinery, such as is found in automotive factories. The reason for this is obvious; since machinery of this type is very expensive and the designs of aircraft engines change so frequently, the installation of such equipment would not be justified. Many factories do use large production machines, but as a rule these are of the universal type which can be readily adapted to changes.

A great number of smaller, individually operated precision machines are used, such as lathes, drills, shapers, grinders, etc. This equipment is extremely flexible in its range of operation though not as economical as regular production machinery. Many small hand tools such as drills, hand grinders, etc. are used.

There are very few, if any, factories that build the entire engine. Many engine parts are purchased in the finished stage from other plants. These often include such items as valves, pistons, piston rings, bolts, studs, spark plugs, gaskets, ball bearings, etc. Other parts are purchased in an unfinished form and are machined or processed at the engine factory. These are usually the rough forgings or castings of such parts as crankshafts, cylinders, cylinder heads, crankcases, etc.

The materials used in engine construction are the best obtainable. There is very little compromise between cost and quality except on some of the smaller engines in which the retail price is of major importance. New materials are being developed continuously which are stronger, lighter, tougher or otherwise more satisfactory than those used before. As fast as these new materials are proved to be superior they supersede the old. This is a progressive attitude, but one that necessitates the maintenance of a large research and testing department.

All engine parts must pass a rigid inspection before they are used. This is an important consideration in their manufacture, for the progress of aviation depends directly upon the reliability of the engine. The failure of one small part in an otherwise mechanically perfect engine may be sufficient to cause the failure of the entire power plant. A few such failures will, of course, seriously affect the manufacturer's reputation and consequently his sales.

A.T.C. Requirements - In addition to testing engine parts the entire engine must be tested for operation. Engines of new design must be licensed before they may be sold for use commercially. Upon successful completion of the licensing tests the engine type is given what is called an Approved Type Certificate, or "A.T.C." Some of the requirements for obtaining an A.T.C. are given below. (From C.A. R. bulletin)

"An engine of more than 100 horsepower shall be equipped with a dual ignition system having at least two spark plugs per cylinder."

"A test report, satisfactory to the Secretary, including a log and an affidavit, describing in full detail the manufacturer's block test of an engine of the type for which certification is desired. The test shall be of at least 100 hours duration, of which 50 hours shall be at full throttle at an average speed within plus or minus 3 per cent of the proposed rated speed and 50 hours at 75 per cent of the proposed rated power at propeller load speed. The submission of this test report will not be deemed necessary by the Secretary for modified engines of a type previously tested which do not incorporate changes in the general arrangement, number of cylinders or displacement, or an appreciable increase in power or speed."

"A detailed report, supported by affidavit, of a 10-hour flight test of the engine. This test shall include a climb at full throttle to 15,000 feet or to the service ceiling of the airplane. The report shall completely describe the test and the results thereof and shall include dates, the names of persons involved and particulars of the airplane. The engine used for this test may be the same engine as submitted for the endurance test or may be another engine of the same type."

"A 50-hour full throttle endurance test of the engine described in accordance with paragraph 13.202 shall be run in periods of at least 5 hours each on consecutive working days except that interruptions to such schedule are permissible if explained to the satisfaction of the Secretary. The test shall be witnessed by an authorized Bureau inspector."

"The engine shall be run at a speed approximately equal to the proposed rated speed and with the manufacturer's recommended setting of the ignition timing, mixture control and intake heat control. The grade of fuel used during the test will be the lowest approved for use in the engine when certificated. Excessive adjustment to the engine or dependence upon excessive fuel or oil consumption for proper cooling during the test will be considered cause for denial of certification by the Secretary."

"Not more than three forced stops caused by the engine shall be allowed during the endurance test. A run of 5 hours shall be added to the test for each forced stop made. Failure of accessories shall not necessarily be considered a forced stop. If the power in a dynamometer run drops as much as 10 per cent, due allowance being made for atmospheric conditions, this shall constitute a forced stop. If a propeller is used to absorb the power during the endurance test,

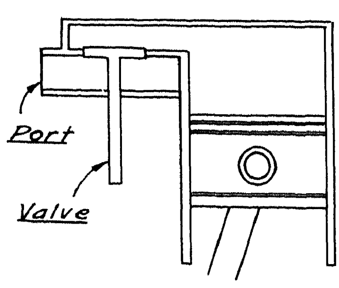
variations in speed of plus or minus 3 per cent are permissible. A variation in speed in excess of this amount due to atmospheric conditions will not be considered a forced stop but the propeller shall be changed to correct for the conditions. Excessive water, fuel or oil leaks developing at the engine shall constitute forced stops. In all cases the Secretary shall be the judge as to what constitutes a forced stop. An engine failure of a type which could cause an immediate forced landing in flight or require the replacement of a major part of the engine shall terminate the test."

"Complete readings of the performance of the engine shall be recorded at least every half-hour throughout the endurance test. The following readings are essential:

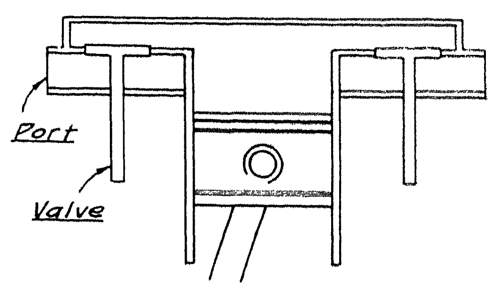
(a) Crankshaft speed in revolutions per minute.
(b) Manifold pressure.
(c) Temperatures of the two hottest cylinder heads and barrels if air cooled, or of the inlet and outlet liquid if liquid cooled.
(d) Fuel consumption.
(e) Oil consumption
(f) Oil inlet and outlet temperatures.
(g) Oil pressure.
(h) Air velocity or pressure difference over the cylinder heads if air cooled.
(i) Barometric pressure.
(j) Temperature (dry and wet bulb).
(k) Engine air inlet temperature and pressure."

CYLINDERS

Although the overhead-valve cylinder is the most widely used today, there are other types worthy of mention. Fig. I shows the principle of the L-head construction. In this the combustion chamber is extended to one side of the cylinder bore and both valves are placed in this offset. The valves are usually located in such a manner that they open the port when they are pushed up. This eliminates the need for rocker arms, as the valves can be actuated directly by pushrods. This type of construction is used frequently in small horizontally opposed engines.



L-Head Cylinder
FIG. I



T-Head Cylinder
FIG. II

Another type of cylinder is the T-head, shown in Fig. II. This is similar to the L-head, except that the valves are located on opposite sides of the cylinder bore. The valves are actuated in the same manner as those on the L-head cylinder, but usually require the use of two camshafts.

PISTONS

Pistons are usually made of some form of aluminum alloy, although in a few of the smaller engines cast iron pistons are used. Fig. I shows a cross section of a typical piston with the various parts named. The top of the piston is called the head. There are various types of piston heads; the concave, indicated by the dotted line, a; the flat head, indicated by the solid line, b; the half-dome, indicated by the dotted line, c; and the full dome indicated by the dotted line, d. The wrist pin is supported by an enlarged section called the boss. The lower part of the piston, or the portion below the boss, is called the skirt, s, which usually contains one or two grooves for oil control rings. Many times the piston is reinforced by integrally cast ribs, or fins, f, on the inside of the head. These fins also serve to transmit the heat more rapidly away from the piston head.

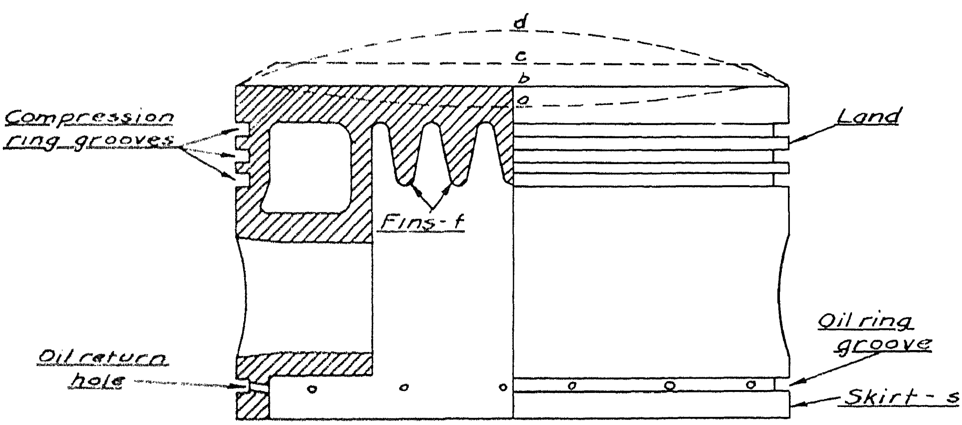


Fig. II shows two Wasp pistons. Notice the reinforced boss section and the webbed reinforcings and cooling fins on the under side of the head. The flat head contains two recesses for the exhaust and intake valves. These indentations provide sufficient clearance to allow the valves to open wide and still not strike the piston when it is on top center.

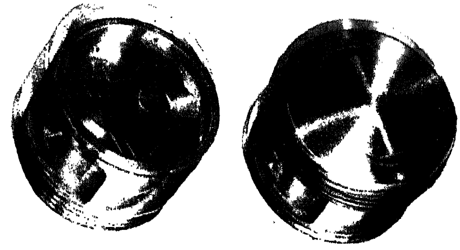


Fig. II

PISTON RINGS

Piston rings are carefully machined from a special grade of cast iron containing carbon, manganese, phosphorous and sulphur. The composition of the alloy used by the U. S. Hammered Piston Ring Co. contains a percentage of graphitic carbon, a natural lubricant which serves to reduce ring friction.

Piston rings are machined to the exact size required and then cut at one point. After being cut they are peened, or hammered, on the bottom (or inside of ring) to expand the ring diameter. When the completed ring is compressed to cylinder size it returns to its originally machined shape, a true circle, but it now has a tendency to expand when inserted in the cylinder. The force with which a ring presses against the cylinder walls is called ring tension. The usual tension is approximately 4½ lbs. per sq. in. of bearing surface, depending further on individual requirements.

One of the most common types of ring joints or gaps is shown in Fig. I-A. This is called the scarf cut, or diagonal. Another popular type is the step cut, illustrated in Fig. I-B. When piston rings are installed the ends are filed so that the gap clearance, or the distance between the ends of the ring when compressed to cylinder size, is about .004" to .006" per inch of ring diameter. This is necessary to allow the ring to expand when heated. Insufficient gap clearance will result in rapid wear, broken rings or piston damage. Note: The exact gap clearance is given by the engine manufacturer in the instruction book.

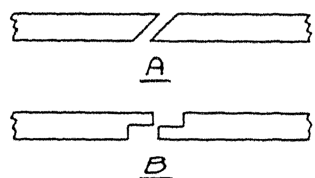


FIG. I

Piston rings are divided into two classifications with respect to their use, compression rings, and oil control rings. Compression rings are usually the top rings on a piston and serve mainly to form the compression seal. These rings are square or rectangular in cross section, as shown in Fig. II-A. The oil control rings are usually the bottom piston rings and serve not only to improve compression but to prevent the lubricating oil on the cylinder wall from working into the combustion chamber. Probably the most common type of oil control ring is the bevel ring, sometimes called the oil wiper ring, Fig. II-B. Another popular type is the grooved, or ventilated ring, Fig. II-C. This ring has small holes or slots which allow the oil which accumulates in the groove to drain into the piston ring groove, where it returns to the crankcase through small holes in the piston.

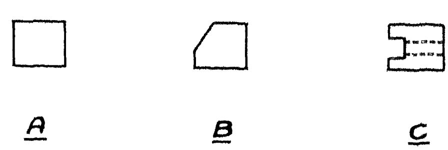


FIG. II

AIRCRAFT VALVES

Aircraft valves must be designed to withstand the high temperature and

hard usage received in an aircraft engine. They must be improved constantly to meet the increasing requirements of larger and more powerful engines. Considerable research and technical engineering are necessary to produce valves that will satisfactorily meet the stringent requirements of aircraft engines. For this reason most engine manufacturers purchase engine valves from an outside source in preference to manufacturing them in their own factories.

The following condensed discussion of aircraft valves was written especially for this book by A. T. Colwell of the Thompson Products, Inc., one of the largest manufacturers of aircraft engine valves.

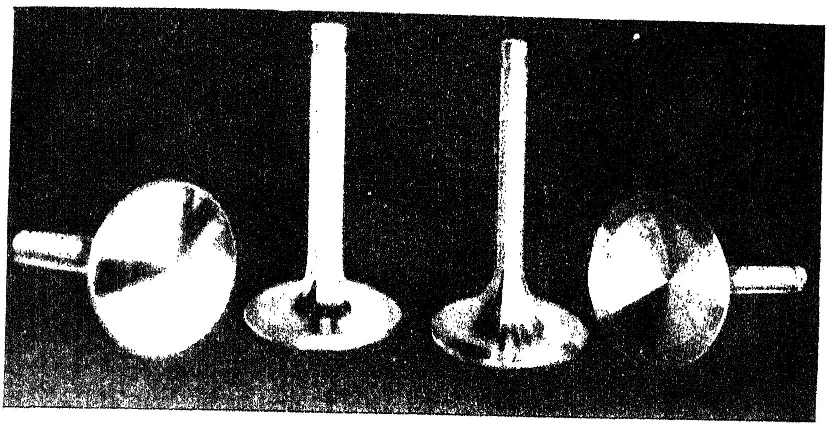


Fig. I Thompson Aircraft Valves

"Exhaust valves used in aircraft engines must be made of a steel that will have strength and resist oxidation and corrosion at high temperature. Solid steel exhaust valves reach temperatures as high as 1450° F., or more. This is too high for satisfactory service and an effective cooling means must be incorporated within the valve itself. Sodium cooling reduces the valve temperature 300 to 400° F.

"The steel most commonly used is a high nickel high chromium steel that has strength and resistance to oxidation. Unfortunately this steel cannot be hardened beyond what it normally is and this is not a sufficient hardness for the tip end. In order to give the tip end the required hardness to resist wear through contact with the rocker arm mechanism a high carbon steel tip is welded on. This tip can then be hardened by heat treatment. The tip may also be welded stellite.

"The valve steel is also a comparatively poor conductor of heat; about one-third as good as ordinary steel. Heat dissipation is therefore slow and the valve head reaches abnormally high temperatures. Valve cooling can be accomplished by making the interior of the valve hollow and adding a material that will transmit heat rapidly to the cooler parts of the valve.

"Exhaust valves are usually made with a cavity extending from within about 1-1/2 inches of the tip down the stem and well into the head (hollow stem valves), or better yet with a greatly enlarged cavity in the valve head in addition to the stem cavity (hollow head valves). The cavity reduces the weight of the valve as well as providing a place for the cooling medium.

"Metallic sodium is very satisfactory as a cooling medium. It is an excellent conductor of heat - over six times better than the valve steel; it is light in weight - no heavier than water; it melts at 208° F., which means that it is liquid at operating temperatures and thus transfers heat by convection or circulation as well as conduction. Valves filled 60 to 70 per cent full of metallic sodium are very effective in transferring heat from the head of the valve to the stem and thence to the guide where it is dissipated into the cylinder head. Valves containing metallic sodium are completely closed in by forging and welding at the tip end; there is little chance of its leaking out.

"Exhaust valve faces (seating surfaces) are either the valve steel itself or stellite. Stellite faces have about 1/16 inch of stellite welded to the steel. This improves the face both as a sealing surface and in its resistance to the action of the hot gases.

"Valves that have stellited faces are lapped at the factory. This lapping operation is done to aid in inspecting the surface of the stellite for defects that could not readily be seen on the ground surface. The characteristic lapped finish appears on the stellited faces of new valves.

"If stellited valves are refaced for any reason only a small amount (.010) should be removed. The stellite on a new valve is only 3/64 to 1/16 thick and also there is danger of defects appearing on the new surface if too much stellite is removed.

"The valve steel even though it cannot be hardened by ordinary heat treatment is normally hard enough to make a satisfactory bearing surface for the stem. The stem hardness can be greatly increased however, by a nitriding treatment. This treatment gives the stem a file hard surface of about .005 inch penetration. The nature of this nitrided surface gives it an excellent wear resistance.

"Other exhaust valve steels are used particularly in earlier valves. High tungsten steel and cobalt chromium steel commonly used in earlier valves have different characteristics from the steel most widely used at present. They can be hardened and have strength at temperatures up to 1000° F., but strength and resistance to oxidation are low at the higher temperatures.

"Intake valves are made of tungsten steel, chrome nickel steel and other steels. The valves are solid and consequently the stem sizes are smaller than those of exhaust valves. Tungsten steel can be hardened and has sufficient strength at operating temperatures. If better oxidation and corrosion resistance is required, CNS steel is used. This steel can be hardened, but in some cases a high carbon steel tip is welded on to obtain a greater hardness.

"Insert seat materials are limited to those that have high enough expansion characteristics so that they will stay in the aluminum alloy cylinder head. Aluminum bronze has good heat dissipating properties and therefore does not overheat easily. Nickel chromium steel can stand much higher temperatures and works well with the stellite face on the valve.

"The design of the valve depends somewhat upon the type it is to be. For example, a hollow head valve would have a crowned head whereas a valve with hollow stem only would probably have a shallow cupper head. Intake valves usually have a semi-tulip-shaped head.

"Valve faces are usually 30 or 45°. The valve face is from 1/8 to 7/32 (measured parallel to the valve axis) wide on average size valves. Wide seating surfaces permit better heat dissipation from the valve to the cylinder head. There is a limit, however, beyond which no gain in heat dissipation is obtained by increasing the width of seating surface.

"The position of the valve face on the seat of the insert in the cylinder head is such that the valve face projects beyond the seating surface about .015 to .025 inch (measured parallel to the axis) on both the port and combustion chamber side. Refinishing the seat of the insert will reduce the amount the valve face projects beyond the seat on the combustion chamber side unless the top of the insert is refinished at the same time. Therefore, if the seat is refinished to the extent that the valve face does not project beyond, then the top of the insert should be removed until it does. Refinishing the valve face will cause more of the face to project into the port but does not change the amount projecting into the combustion chamber.

"As the valve head becomes heated in operation it expands more than the seat in the cylinder and thus tends to climb higher on its seat. Temperature changes in the valve therefore shift the contact surfaces a slight amount. Also, the contact surfaces may vary somewhat due to weaving of the valve in operation. For these reasons it is desirable to have straight smooth seating surfaces with no more lapping than necessary to make a tight seal.

"The Wright Cyclone exhaust valve has an interference fit. In order to get good seating at operating temperatures the valve face angle is made 29-1/4° to 29-1/2° for a 30° seat. Therefore, this valve cannot be lapped to the seat except for a line contact at the outer edge.

"Retainer lock grooves are of many different designs. These grooves are accurately ground and the retainer locks accurately made. If either the grooves or locks are injured in any way they should be repaired before assembly, otherwise they may be the cause of failure.

"Safety grooves are placed on valves to prevent them from dropping into the cylinder in case failure occurs at the retainer lock or a spring breaks. A snap ring is placed in the safety groove as soon as the valve is assembled which prevents it from slipping through the guide."

SPARK PLUGS

One of the most important parts of the engine is the spark plug. Without a spark, there can be no ignition and, hence, no operation of the engine.

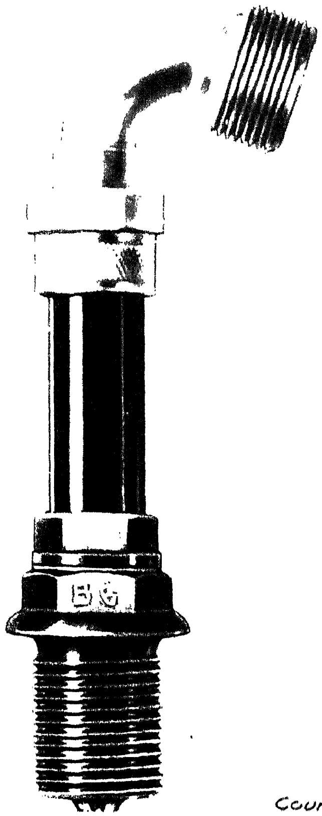


Fig. I

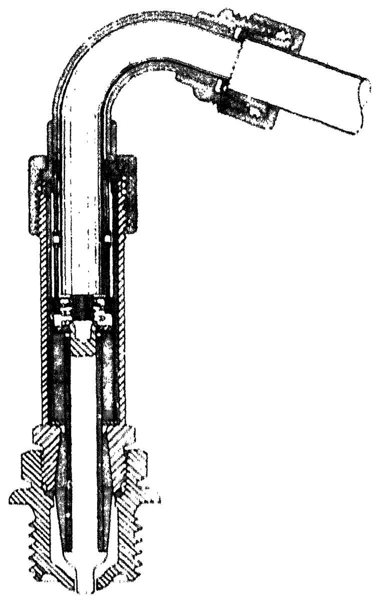


Fig. II

Courtesy B.G. Spark Plug Corp

Spark plugs for aviation engines not only must be more dependable than those used in automobiles or boats, but they are usually called upon to withstand much more severe service. For these reasons they are made of expensive materials and with great care.

A spark plug consists of a shell, which screws into the cylinder head, and a core which usually screws into the shell. The core is composed of the bushing, which is a threaded metal sleeve firmly attached to the rest of the core, an insulator of mica or porcelain and a center electrode, to the terminal of which is attached the high tension wire from the magneto. The other end of the center electrode terminates in a cylindrical portion about 3/32" in diameter which is one of the points. The other point or points are part of the shell. The insulation of most aviation plugs is made of disks of mica, compressed into a cylinder enclosing the center electrode.

Copper gaskets are used between the core and the shell and between the shell and the engine so that there will be no leakage, or loss of compression.

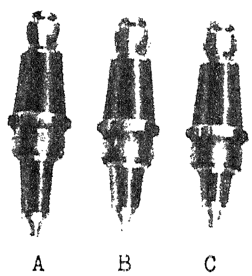
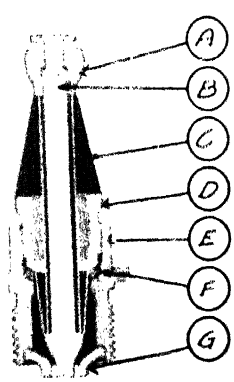


Fig. III

The high tension current enters the terminal from the ignition wire, runs through the center electrode to the center point and jumps the gap to one of the points on the shell, and, thence, through the metal of the engine, which acts as a ground, back to the magneto. If the gap is closed so that the points touch, or if the plug is fouled by oil or carbon so that the current does not have to jump, there will be no spark. If the gap is too wide, the spark will be too weak to give proper ignition.

On airplanes equipped with radio, the plugs and all ignition wiring, usually called the harness, are shielded with flexible metal tubing, so that the sparks will not disturb the operation of the radio. A cross section of a B.G. shielded plug is shown in Fig. II and the outside of the same plug in Fig. I. The type of plug known as a hot plug has a relatively long section of insulation exposed to the heat of the cylinder. This absorbs the heat and in low compression engines or engines which use a large amount of oil the hot plug burns off any oil immediately, thus preventing fouling. A cold plug has a much shorter insulation inside the cylinder and is used on high compression engines, where the temperature of the cylinder is likely to be high. Fig. III shows three lengths of cores. A is from a hot plug, B from a medium, and C a cold.

The thread on aviation plugs is metric, with a diameter of 18 mm. and a pitch of 1.5 mm. The length of the threaded portion is known as the reach and is 1/2" on American engines.



SECTION OF MICA PLUG

A - Terminal
B - Center electrode
C - Core
D - Bushing
E - Shell
F - Gasket
G - Adjustable points

COOLING LIQUID PUMPS

Liquid cooled engines require a cooling liquid pump such as that used on the Curtiss Conqueror, and illustrated in Fig. I. Pumps of this type are used to insure constant circulation of the coolant while the engine is running. A two-piece housing encloses an impeller, i, which is turned by a shaft geared to the engine accessory drive. A soft gasket prevents leakage at the housing parting surfaces. A packing gland insures a water-tight seal around the impeller shaft. This gland consists of several split, graphite packing washers, w, placed around the shaft and fitted inside of a retaining cup. The packing washers are compressed by tightening a packing gland nut, n, which is threaded on the retaining cup. As the packing washers are compressed, they expand sufficiently to prevent leakage around the shaft, yet still allow the shaft to rotate. A spring steel safety clasp, s, is commonly used to prevent accidental loosening of the gland nut. Pump packing cord is sometimes used in place of packing washers, however in either case the packing is treated with graphite which not only helps provide a better seal, but aids materially in lubricating the shaft. Additional lubrication is supplied by forcing a waterproof grease through a drilled passage to the shaft at the lower end of the retaining cup.

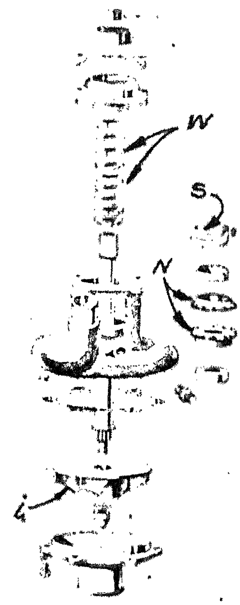


Fig. I

In service, the packing gland must be tightened at frequent intervals as the continued rotation of the impeller shaft tends to harden the packing. Tightening the gland nut further compresses the packing which, in effect, renews the shaft seal. A neglected packing gland leak causes considerable trouble, as the seepage of liquid eventually corrodes the shaft. A shaft thus roughened by corrosion will tear and grind the packing until it is impossible to make a permanently tight seal. This trouble is to some extent corrected by the use of stainless steel impeller shafts.

BEARINGS

Bearings serve not only to reduce friction between moving parts, but also to provide an inexpensive replacement, eliminating the necessity of discarding more expensive parts after frictional wear. The type used in aircraft engines may be roughly divided into three classifications; plain, roller and ball bearing.

Plain Bearings - Babbitt, brass, and bronze are commonly used for plain bearings. The general principle observed in determining a bearing material is the selection of a material that is hard enough to withstand considerable wear and yet softer than the material with which it is in contact. Plain bearings must also rapidly conduct heat away from points where friction occurs. For example, it would be possible to make valve guides an integral part of a cylinder head casting. If this were done the bearing surface for the valve stem

would be of aluminum alloy, which is much softer than the valve stem. The frictional heat produced by the operation of the valve would be quickly conducted to other parts of the head and finally dissipated by the cooling fins. However, the valve stems, being so much harder than the valve guides, would quickly wear away the aluminum. The entire cylinder would have to be replaced to renew the valve guides. This expensive replacement is made unnecessary by the use of bronze valve guide inserts. The bronze will not wear away as quickly as aluminum and the separate guide may be replaced when it becomes worn.

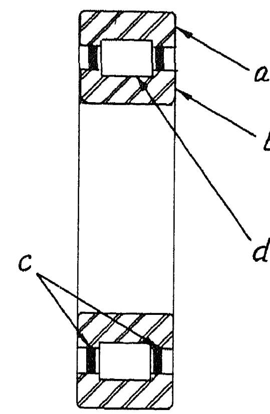


FIG. I

Another example illustrating the importance of bearings is the joint between the connecting rod and crankshaft, both of which are made of hard steel. If there were no soft material between these parts, there would not be much wear, but excessive heat would be produced, and as hard steel is not a good conductor the heat would remain concentrated at this point. Any such concentration of heat would cause two metals of equal hardness to seize, or weld themselves together, resulting in disaster to the engine. Even if it were possible to run the engine without the connecting rod and crankshaft seizing, natural wear would finally necessitate the replacement of one or both of these parts. Either eventuality is avoided by the use of a bearing between these two parts.

The following list gives the location and types of some of the plain bearings used in aircraft engines:

Crankshaft journal bearings: Babbitt or steel-backed lead bronze
Connecting rod main bearing: Babbitt, steel-backed lead bronze, or steel-backed cadmium
Wrist pin bearing: Brass or bronze
Knuckle pin bearing: Brass or bronze
Drive shaft bearing: Brass or bronze

Roller Bearings - Fig. I shows a cross section view of a standard type roller bearing, which consists of an outer race, a, an inner race, b, two retainer rings, c, and the rollers, d. The entire bearing is made of hardened steel. It is used where a heavy, low friction bearing is needed, such as on the crankshaft journals in a radial engine.

Ball Bearings - Fig. II shows a cross section of a typical ball bearing consisting of inner and outer races and the steel balls. Bearings of this type are not as strong as roller bearings, but eliminate more friction. There are many types of ball bearings made for use on almost any rotating shaft. Most aircraft engines use ball bearings to absorb the propeller thrust.

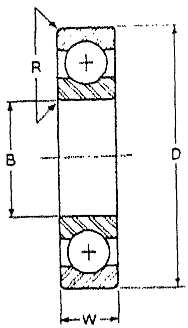


Fig. II

Fig. III

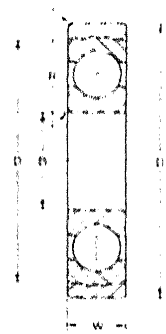


Fig. IV

Shielded ball bearings of the type shown in Fig. III are used in exposed places. The shielding serves to keep the lubrication in and to keep foreign matter out.

Bearings which are contained in a special housing such as illustrated in Fig. IV are self-aligning bearings. As will be seen by the illustration, the bearing housing permits a slight movement of the outer bearing race to compensate for any misalignment between the shaft and the bearing retaining surface. Self-aligning bearings are frequently used where precision alignments are required, such as on impeller shafts. They are also used where it is impractical to obtain perfect bearing alignment such as airplane control hinges, bell cranks, etc.

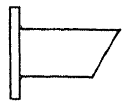
EXHAUST SYSTEMS

The exhaust system, broadly speaking, embraces all those parts of the engine and accessories which conduct the exhaust gases from the combustion chamber to the open air. This includes such items as exhaust valves, exhaust ports, exhaust valve mechanisms, exhaust stacks, manifolds, etc., and for this reason it is discussed under "Engine Parts." However, the term "exhaust system" is usually construed to mean the pipes, manifolds, etc., which take the exhaust gases from the cylinder to the open air.

Short Stacks - Probably the simplest form of exhaust system is the so-called "short stack." This type of exhaust was used to a great extent on many of the early aviation engines, notably the "Hisso" and Liberty, and is common on in-line engines on military airplanes today. These stacks consist of short sections of tube or pipe fastened directly to the cylinder port, their main purpose being simply to lead the exhaust gas from the engine to the outside of the cowling.

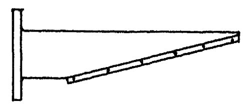
Short stacks have the advantage of being simple, easy to make and maintain, light and inexpensive. They also serve to some extent to control the direction of the exhaust without causing any back pressure. The main objections to short stacks are that they have no muffling or quieting effect on the exhaust noise, they do not lead

the gases away from the cockpit and they do not afford sufficient protection to the exhaust mechanism. Stacks of this type permit too rapid changes in temperature of the exhaust port, which, in many cases, results in warped valves, warped seats, etc. This is particularly noticeable when the ship is performing maneuvers such as slips and stalls. Another disadvantage of short stacks is that they do not shield the flame of the exhaust from view. While the exhaust flames of a properly running engine are not apparent in daytime, they are plainly visible at night and are likely to interfere with the pilot's vision. This is not only disagreeable but may be dangerous, especially in landing.



Short Stack

Fig. I

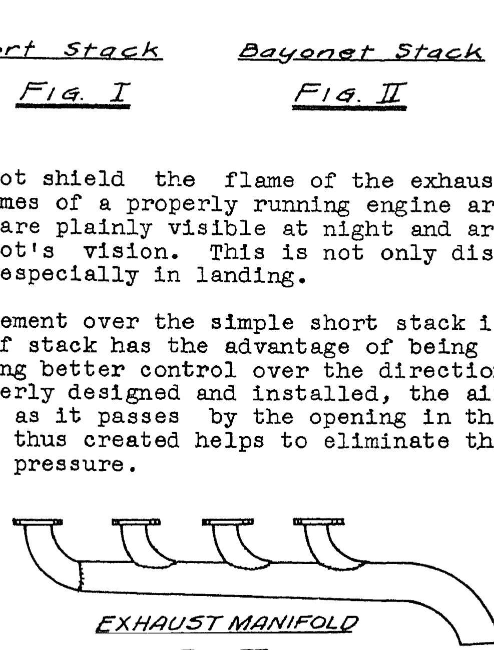


Bayonet Stack

Fig. II

Bayonet Stacks - An improvement over the simple short stack is the "bayonet" stack. This type of stack has the advantage of being a little quieter and also of having better control over the direction of the exhaust gases. When properly designed and installed, the air stream causes a slight suction as it passes by the opening in the stack. The reduced pressure thus created helps to eliminate the waste gases, preventing any back pressure.

Exhaust Manifolds - Fig. III shows a simple arrangement to exhaust gas from a 4 cylinder in-line engine through short connecting stacks into one common collector manifold. From this manifold the exhaust gases may be led through a single large tube to any point desired. To prevent the gas from smoking up parts of the airplane, and to reduce the fire hazard, the exhaust discharge is directed to a point above or below the wing. On some ships the pipe is carried back past the trailing edge of the wing. A long exhaust such as this tends to eliminate some of the noise.



EXHAUST MANIFOLD

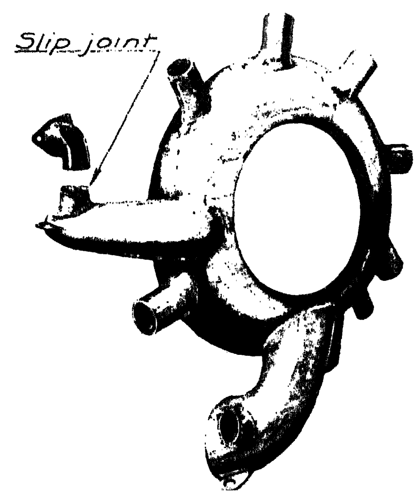
Fig. III

Manifolds protect the valves from sudden changes in temperature by preventing the air stream from reaching the exhaust ports. However, they must be carefully designed to prevent any possibility of back pressure. If the exhaust gases from the individual cylinders cannot escape from the manifold as rapidly as they enter, a positive pressure is built up inside the manifold. This pressure slows up the exhaust escape from each cylinder, thus preventing the thorough scavenging or cleaning of the cylinders at the end of each power cycle. Exhaust gases, if left in the cylinder, mix with the incoming fuel charge resulting in considerable loss of power. Back pressure in an exhaust manifold may be caused by too small a discharge tube, by a partially closed or obstructed opening, or by sharp bends or

kinks in the pipe. Furthermore, if the exhaust tube is so located that the air stream retards the exhaust gases, it has the same effect as a partially closed opening.

Collector Rings - Collector rings serve the same purpose for the radial engine that the exhaust manifold does for the in-line engine. The collector ring is considerably more difficult to design, both from the standpoint of engineering and construction details. It must be built so that it collects the gases from each cylinder into a common manifold which, of course, must be made in the shape of a ring. This necessitates many turns and bends in the exhaust line, each of which is a potential source of back pressure. A flexible or slip joint must also be provided between each cylinder and the ring to facilitate the removal of one cylinder without removing the entire collector ring. These joints also allow a certain amount of adjustment to compensate for any alignment necessary as well as providing for unequal expansion when the ring becomes heated.

Collector rings are usually mounted directly behind the cylinders and are supported by fastenings to the engine. One notable exception is the Wright Whirlwind, which has the collector ring in front of the cylinders. The exhaust tube which carries the gases back to the point of discharge is supported in at least one or two places by attachments to the engine mount or fuselage. This makes it necessary to provide some type of vibration joint between the collector ring and the exhaust tube, as the periods of vibration of the engine and the engine mount are different. Unless the tube is provided with such a joint, this variation in the periods of vibration will cause it to crack. Some exhaust systems have a flexible metal hose connecting the tube to the ring to provide the necessary absorption of vibration. This method is not entirely satisfactory, as the flexible hose connection causes considerable trouble by burning out or rusting. A more common type of vibration joint is the slip joint shown in Fig. IV.



COLLECTOR RING. FIG. IV
Courtesy Wright Aeronautical Corp.

Construction of Exhaust Systems Some exhaust manifolds, lines, rings, etc., are made of low carbon steel as this metal is strong for its weight and yet soft enough to withstand considerable vibration without cracking. The thickness of the metal varies with the horsepower of the engine and the design and installation of the system. If the metal is too thick it will have a tendency to crack and warp out of shape due to the uneven heating and cooling. For this reason, as well as to keep down weight, the metal used is as thin as possible, yet heavy enough to prevent the high exhaust flame temperatures from burning through. Also if the

metal is too thin it will have a tendency to buckle. The range of thicknesses which may be safely used is rather limited, ranging from .035" to .065" in thickness.

Black iron exhaust stacks and collector rings have not proved to be very satisfactory due to their rapid deterioration when subjected to the corrosive effects of tetra-ethyl fuels and the high exhaust temperatures of the larger engines. These objectionable features have been almost entirely eliminated by the use of stainless steel and Inconel.

Stainless steel collector rings are made in several half sections and welded along the seams. The half sections are stamped from flat sheet stock, using a zinc female die and a lead male punch. After the collector ring has been welded it is checked for alignment and then "normalized" by heating to a temperature above the scaling point of stainless steel (1900° F). This is done to eliminate any localized stress which may have resulted from the welding. After normalizing, the ring is pickled to remove the scale and is then subjected to a bath of nitric acid to prevent corrosion in use. The latter process is called <u>passivating</u>.

<u>Exhaust Heat for Carburetion</u> - For cold weather operation of airplane engines it is necessary to supply heat to the carburetor manifold. This is done by directing the exhaust from one or more cylinders, by means of specially constructed heater tubes, through the carburetor manifold. These heater tubes are called hot spots, one type of which is shown in Fig. V. In some cases the exhaust gases are allowed to escape into the open air after they leave the carburetor manifold; in others they are returned to the exhaust manifold, where they are exhausted through the main discharge tube. Often the exhaust heat is utilized in a similar manner to preheat the air before it enters the carbure-

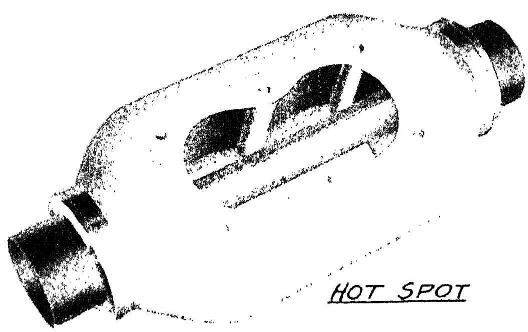


FIG. V

Courtesy Pratt • Whitney

<u>Care and Inspection of Exhaust Systems</u> - Although the exhaust system is only a small portion of the power plant it demands considerable attention, as cracks and rust spots will develop quickly and spread rapidly unless checked in time. If the exhaust manifolds are made of stainless steel the oxidizing, or rusting, is practically eliminated. Plain steel stacks should be protected against oxidizing and this may be done by painting or metallizing. The paint used is a special heat-resisting paint or synthetic enamel. Several manufacturers make a special exhaust stack paint for this purpose. Due to the high stack temperature and the rapid expansion and contraction

of the metal, very few paints will stand up, especially if subjected to salt water spray, as on a seaplane. This makes it necessary to watch constantly the condition of the paint and to retouch often. Painted stacks should really be removed every three to six months, depending upon the amount of use, and thoroughly cleaned (preferably with sand blast), checked for cracks, and re-painted.

The most satisfactory process for preventing oxidation is metallizing. In this process the surface is first prepared by roughening it slightly with a sand blast and then spraying a thin coating of molten metal on the surface. The metal used in this connection is usually aluminum, although in some cases cadmium is used. In either case metallizing is more durable than paint.

The exhaust system should be inspected for cracks at least once every twenty to twenty-five hours of flying. Cracks are most likely to develop around welds in seams and joints. This may be due to the metal being in a slight tension in such places, or it may be due to the hardening effect produced by the high temperature of welding, or general deterioration of the exhaust stack. If a crack is found the stack should be removed and the crack repaired by an expert welder. If it is impossible to repair the stack immediately a small hole, about 1/8" in diameter should be drilled through the stack at the end of the crack, or at each end of the crack if one end does not terminate in a weld. If it has been necessary to repair the stack several times before, the complete stack should be replaced if possible, since continued welding makes a stack brittle.

If there are any flexible metal tubes in the system they should be inspected as often as possible. These tubes are necessarily made of very thin metal, with the result that any neglected rust spots spread rapidly, thus endangering the life of the hose. Often these flexible metal tubes are installed in such a manner that the heat from the exhaust gases is concentrated on one portion of the tube. This is first indicated by the darker color of the tube at the point in question. These points must be watched carefully as a hole enlarges rapidly if the tube burns through.

All slip joint connections should be carefully checked to make sure they have not rusted to the point of failure. All vibration sleeves should be inspected for alignment and secure anchorings. The entire exhaust system should be inspected for its anchorage. This is usually done by jarring it with the hand to see if it rattles. Any rattles must be investigated and corrected immediately. Failure of the exhaust system often leads to fatal fires.

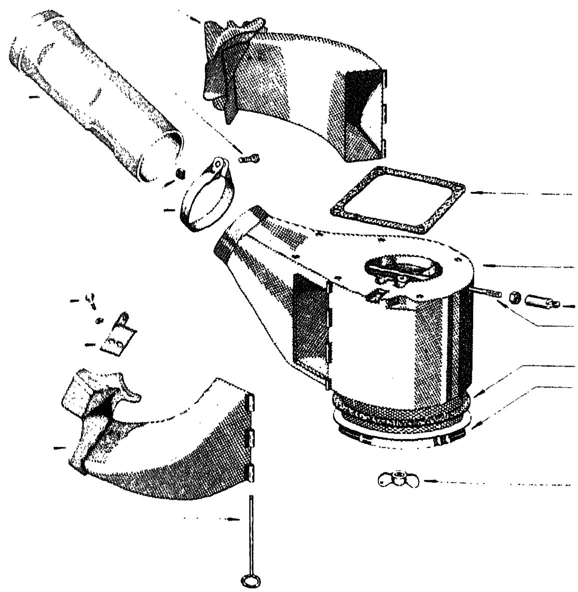
All exhaust flanges to the cylinders should be checked to make sure the gasket is in good shape. A blown gasket is usually indicated by a smoked streak on the cylinder. Needless to say, any damaged gasket should be replaced immediately. If a standard exhaust gasket is not available, a satisfactory substitute can be made from sheet asbestos gasket material. If this is used to replace a copper bound gasket it should be slightly thicker than the original gasket, as it will be compressed more when tightened.

Although brass nuts are usually used on exhaust port cylinder studs because they are not as likely to freeze to the stud as steel,

it is a good practice to put a few drops of penetrating oil on these nuts at each inspection. It is not considered necessary to check the tightness of these nuts at each inspection unless there has been some cause to believe an exhaust gasket is leaking.

CARBURETOR AIR HEATER

A typical carburetor air heater is shown in Fig. I. This device utilizes the exhaust gas heat to raise the temperature of the air admitted into the carburetor. It is provided with a control to regulate the amount of heat delivered to the heating chamber which, within limits, governs the heat of the intake air. The following description of the function and operation of the air heater is from the Wright Aeronautical Corporation's instruction manual.



Wright Whirlwind Carburetor Air Heater
Fig. I

"Air Heater Operation"

The formation of ice in the carburetor can be prevented or relieved by the use of the carburetor air heater. Any roughness may be eliminated or reduced by using the heater. When in doubt always use the air heater.

"The important function of the air heater is to prevent formation of ice in the carburetor venturi. Vaporization of the fuel as it leaves the discharge nozzle of the carburetor causes a temperature drop at this point. This temperature drop depends upon the volatility of the fuel, the fuel air mixture ratio, and other factors.

"Under certain conditions the drop in temperature causes the water vapor in the air flowing past the discharge nozzle to condense and freeze, and ice is deposited on the nozzle, and sometimes on the venturi or other parts of the induction passage beyond the nozzle. There have been cases of ice forming on the butterfly valve to such an extent that the throttle could not be moved.

"This ice formation is dangerous for two reasons -

a. It chokes the air passage causing loss of power, and under the worst conditions may cause complete stoppage of the engine.

b. Small pieces of ice may break off and be carried into the supercharger impeller, thus damaging the blades of the impeller because of the high rotative speed of this unit. This may occur when the engine is apparently functioning in a normal manner so that extensive damage may be incurred without the operator knowing it, unless the proper precautions are taken in the use of the air heater.

"Ice formation is most likely to occur during damp or rainy weather in the fall or spring, when the atmospheric humidity is high and the ground air temperature between 30° and 70° F. (0° C. and 21° C.) Under these conditions the temperature at the carburetor discharge nozzle may be below the freezing temperature of water, and at the same time below the dew point of the air, i.e., the temperature at which the water vapor in the air, when cooled, will condense, forming drops of water or ice.

"When flying in rain or clouds the drops of water entering the carburetor may freeze in the induction passage if the slipstream air temperature is below 70° F. (21° C.), and if no heat is applied to the carburetor intake air.

"With ground air temperatures below 20° F. (-6.7° C.) the danger from ice formation is lessened because the quantity of water vapor in the air at such times is very slight. The same is true at high altitudes (above the clouds) at all seasons. In these two cases the function of the air heater is to improve the vaporization of the fuel and distribution to the cylinders. It will be found that in cold weather, or at high altitudes, that better fuel economy can be obtained with the heater control in the hot position. Under these conditions heating of the carburetor air intake is particularly necessary for proper acceleration and to prevent stalling when the engine is throttled back during a glide.

"In hot weather the control should be kept in full cold position, which will permit the engine to develop the maximum power output without danger of overheating the cylinders."

GASKETS

Gaskets are used between two flat surfaces for the purpose of providing a seal to prevent liquid or gas from escaping. Some of the most common gasket materials are asbestos, copper, fiber, lead, cork, rubber, paper, and vellumoid.

Asbestos sheet in thicknesses from 1/16" to 1/8" is used wherever a heat-resisting gasket is needed. It is, of course, fireproof and therefore is used extensively for exhaust gaskets. Most asbestos exhaust gaskets are bound with thin sheet copper to prolong their life.

Copper is used where it is essential to have a non-compressible yet semi-soft gasket, such as on spark plugs.

Fiber is not seriously affected by gasoline, therefore it is used almost exclusively for gaskets and spacing washers inside of carburetors and other gasoline accessories. It is also an insulator and is used as an insulating washer on electrical apparatus. Gaskets

and washers of fiber are also used as friction bearings in tension mechanisms, such as throttle controls, Bowden cables, etc.

Lead sheet, in thicknesses ranging from 1/32" to 1/8" and over, is used for gaskets which must be removed and replaced often, such as on gasoline and oil strainers, carburetor plugs, etc.

Cork gaskets are used in thicknesses from 1/16" to 3/16". They are usually used as an oil seal between sections of the crankcase or between crankcase and accessories, where there is a need for a gasket capable of occupying an uneven or varying space such as might be caused by a rough surface or expansion and contraction.

Rubber sheet is used where there is a need for a compressible gasket. However, it cannot be used in any place where it is likely to come in contact with gasoline or oil, as it deteriorates very rapidly when exposed to these substances.

Paper gaskets are used extensively between perfectly fitted surfaces, especially if these surfaces do not have to be parted frequently. They are also used for spacing gaskets, such as in fuel pumps, oil pumps, carburetor parting gaskets, etc. Heavy brown wrapping paper makes an excellent substitute for gasket paper, unless a gasket of an exact thickness is needed.

Vellumoid is the trade name of a material widely used for gaskets. It is supplied in thicknesses ranging from .005" to .035", or thicker. It is a very tough, rough, brown leather-like material which has been treated to render it resistant to the action of gasoline or oil. Vellumoid is hard enough to be substantial, yet soft enough to provide a good seal. It may be used plain, though some mechanics recommend the use of shellac. In many instances where gaskets of this material are used it is desirable to put shellac on one side so that the gasket will adhere to one surface permanently, and a graphite-oil mixture on the other side, providing an excellent seal and allowing the surfaces to be parted without destroying the gasket.

FASTENERS AND SAFETIES

The various types of fasteners and safeties used in aircraft engines do not vary much from similar devices used elsewhere. However, they are made as strong as possible and those used in exposed places are protected against corrosion.

Bolts - Engine bolts are made of nickel steel. They are seldom plated with any anti-corrosive material, thereby avoiding the possibility of chips of plating falling into the operating mechanism. All standard engine bolts have a N.F. thread. Note: N.F., or National Fine, thread was formerly known as S.A.E. thread. Only sufficient thread is put on a bolt to insure proper holding power, as it is not desirable to have the threads form any part of the bearing surface.

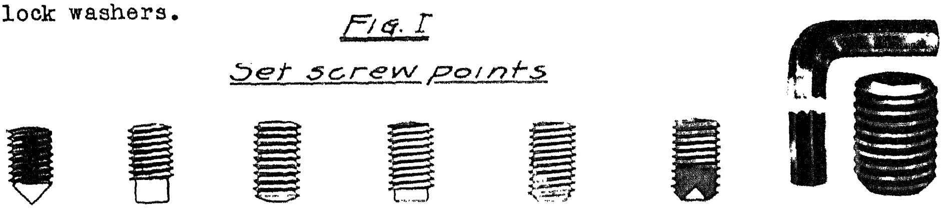
Studs - A stud is a short rod with threads on one or both ends. It is used mostly for anchorage fastenings, such as for holding parts to a housing or case. Studs which are used in aluminum have an N.C. (National Coarse) thread on the base end and an N.F. thread on the other. The N.C. thread, which was formerly known as U.S.S., pro-

vides a better grip in aluminum than would a fine thread. Studs which have threads on the base only are sometimes used for guides or stops.

Cap Screws - A cap screw is a bolt that is designed to screw directly into a threaded part, thus requiring no nut. They are made with either a hexagonal head for a wrench, or with a screw driver slot, and have either an N.C. or an N.F. thread, depending on whether they are to be used in aluminum or steel. The head is usually drilled for safety wire, unless the cap screw is to be used with lock washers.

Fig. I

Set screw points



Set Screws - Set screws such as shown in Fig. I are used to fasten collars to shafts for stops, guides, etc. They are usually made with a coarse thread and then hardened. Various types of heads are used, adapting them to screw drivers, standard wrenches or special hexagonal-shaped wrenches, called Allen wrenches.

Pins - Hardened steel pins are used to fasten collars and small gears to a shaft. Straight pins are held in place by slightly peening or riveting each end. Taper pins, as the name implies, have a slight taper and are inserted in a tapered hole. They are secured by riveting the small end. Occasionally taper pins have the small end threaded, in which case they are fastened in place with a nut.

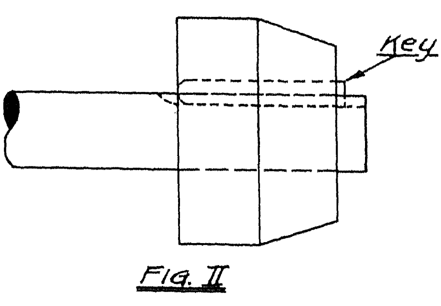


Fig. II

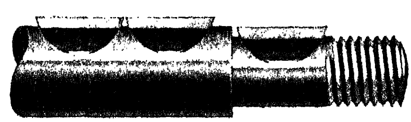


Fig. III

Keys - Keys are used to prevent shafts, gears, etc., from turning on a shaft. They can be roughly divided into two classes, the plain key and the Woodruff key. Both types are made of hardened steel. Fig. II illustrates the plain key. The Woodruff key is shown in Fig. III. It is essential that the key fit tightly in both key

ways, as shown in drawing. A loose fit allows play, or motion, which is likely to increase, causing destruction of the key and consequent failure of the mechanism to operate.

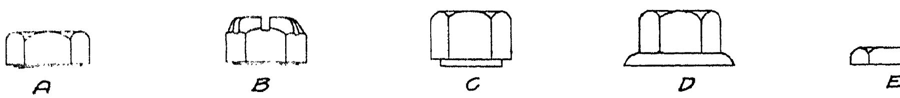


FIG. IV

Engine Nuts and Safeties - Engine nuts are made of the same material as the bolt on which they are to be used. Castellated nuts with slots for safetying, Fig. IV-B, are designed so that the portion below the slots develops the required holding strength. Cylinder hold-down nuts, such as shown in Fig. IV-C and IV-D, are used without a washer. The nut shown in C is used on steel and that in D on aluminum. The check nut, IV-E, is used as a jam nut, or lock nut, to screw down on top of a plain nut, serving as a safety to prevent the plain nut from loosening.

Castellated nuts are safetied on bolts with a cotter pin, as shown in Fig. V. The cotter pin should be put in so that the plane of the loop is parallel with the bolt, and the pin should be tapped lightly with a hammer so that the loop fits tightly into one of the slots. The lower end, or leg, should be cut so that when it is bent straight down it just reaches the base of the nut. The upper end of the pin is bent straight up and over the top of the bolt. Corrosion-resistant materials such as brass or cadmium plated steel, are used for external cotter pins, while those used inside the engine can be made of plain steel. The most common sizes of cotter pins are 1/16, 3/32, and 1/8" (in diameter), however, in special cases larger or smaller diameters are used.

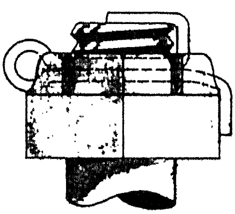


FIG. V

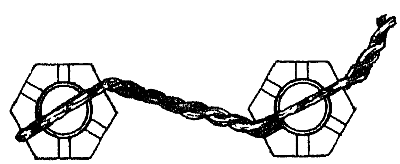


FIG. VI

Safety wire is used for safetying a castellated nut on a stud, as a cotter pin would keep the nut from turning but would not prevent the stud unscrewing from the base. Safety wire is made of soft brass, though stronger soft steel wire is often used inside the engine. In safetying studs, the wire is inserted in the safety hole and the ends fastened to some adjacent point. Where possible, it is desirable to safety two or more studs together, as shown in Fig. VI. The wire should be inserted so that it pulls in the tightening direction, as otherwise the stud could loosen a quarter or a half turn before the safety became effective. The wire is twisted together between each fastening to reduce vibration, which might cause the wire to become brittle and snap. Caution: Twisting the wire too tightly will cause it to become strained, adding to the danger of breakage.

Note: Drilled cap screws are also safetied with safety wire, as described on the preceding page.

Fig. VII shows a palnut, which can be used as a jam nut safety on plain or cylinder hold-down nuts. This safety nut must not be tightened too tightly as the wrench will bend the flanges out of shape making it difficult to remove the safety. Tighten with fingers, then 1/4 turn with wrench.

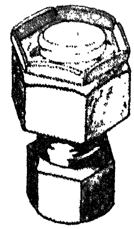


FIG. VII

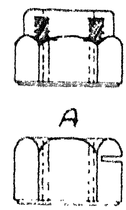


FIG. VIII

Types of self-safetying nuts sometimes used on engines are shown in Fig. VIII. The safety nut shown in A has a fiber insert which, when forced over the bolt threads, grips them tightly, preventing the nut loosening. The slotted nut shown in B is screwed into place and the lip bent down. It can be removed with a wrench but will not loosen under vibration.

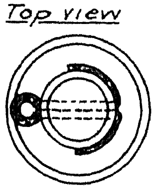


FIG. IX

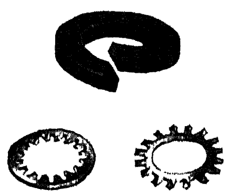


FIG. X

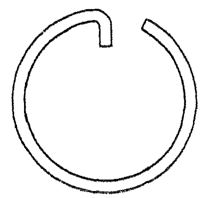


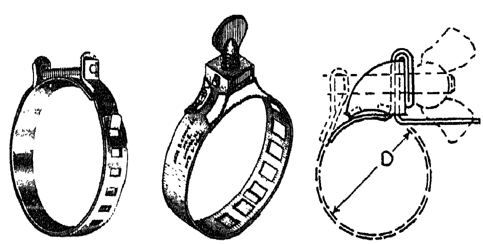
FIG. XI

Clevis Pins - Airplane type nickel steel clevis pins are sometimes used in the engine, though in most cases specially designed clevis pins are used. Fig. IX shows the correct method of safetying a standard clevis pin using a cotter pin. Special clevis pins are safetied in the same manner, unless otherwise specified by the engine manufacturers.

Lock Washers - Fig. X shows three types of lock washers used to safety plain nuts on bolts. They are each made of hardened steel with teeth which grip the under side of the nut, preventing it from loosening. If a lock washer is being used as a safety on a bolt in soft material such as aluminum or brass, it must be placed between the nut and a plain, steel washer. Otherwise when the nut is tightened the lock washer teeth will be forced into the soft material and will not grip the nut.

Lock Rings - Lock rings, such as shown in Fig. XI, are made of spring steel. They are used to form a safety stop, or ring, around a shaft, or they may serve as a clevis pin to safety two parts in position. Great care should be taken to avoid bending or kinking a safety ring, as its holding quality depends upon its spring tension. If this is destroyed the value of the ring is impaired.

Hose Clamps - Three types of hose clamps used for clamping a hose to a pipe or tube, are shown in Fig. XII. They consist of cadmium plated steel bands with some provision for tightening, or decreasing the diameter.

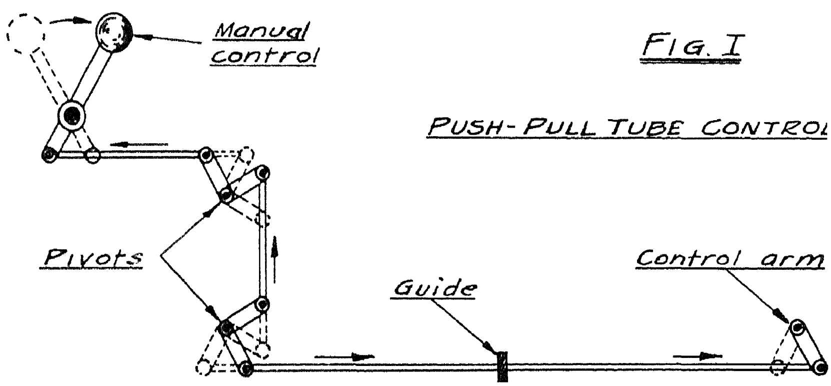


Courtesy Air Associates Inc.

Fig. XII Hose Clamps

CONTROL MECHANISMS

Manual control mechanisms may be divided roughly into two classifications; the solid, or push-pull tube, and the flexible, or wire and cable type. The former is commonly used where it is imperative to have positive control, such as for the throttle, spark and mixture adjustments. The latter is often employed to control secondary adjustments such as radiator shutters, air heater flaps, cowling louvers, etc.



The Push-Pull Tube Control - This is heavier and more difficult to install than the flexible type. Fig. I shows the principle of this type of control. It will be seen that the operation of the unit depends upon the ability of the tubes to take compression and tension stresses. This fact makes it highly desirable to install the control in such a manner that bends and offsets are not required, thereby reducing the possibility of compression stress increasing the bend, or tension stress straightening the tube. Any such distortion would, of course, affect the operation of the control, possibly to the extent of rendering it entirely ineffective. Where it is necessary to use bends or offsets, the tube should be sufficiently strong to withstand deformation.

Long pieces of control tube should be provided with guides to prevent bending. This often necessitates the installation of flexible joints, as shown in Fig. II. These joints permit the short sections of tube to swing in angular alignment with the crankarm movement (as shown by the dotted lines), thus making it possible for the long section of control tube to travel in fixed guides without bind-

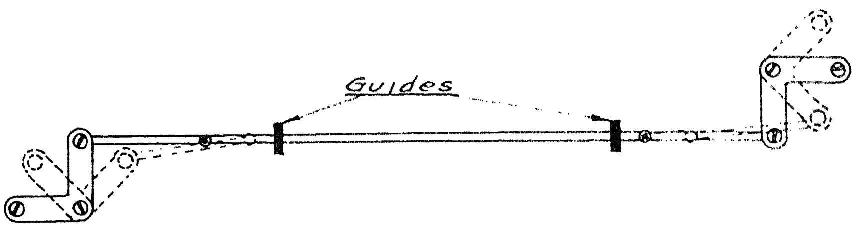


FIG. II

ing. Occasionally, where the angular travel of the tube is slight it is possible to use a single-piece rod with no flexible joints. In this event the angular alignment is made possible by the spring of the tube and by use of a larger clearance in the guides.

A single guide may be used on a rigid tube, as shown in Fig. I. In this installation one end of the tube moves up as the other end moves down. Consequently there will be only a relatively small vertical movement at the center of the tube. This one large clearance guide permits the slight alignment necessary, yet reduces the tendency of the tube to bend.

Guides are usually made of fiber, hard rubber or thick plywood. In some of the more elaborate installations, guides are equipped with anti-friction bearings of brass, bronze, or specially made ball bearings.

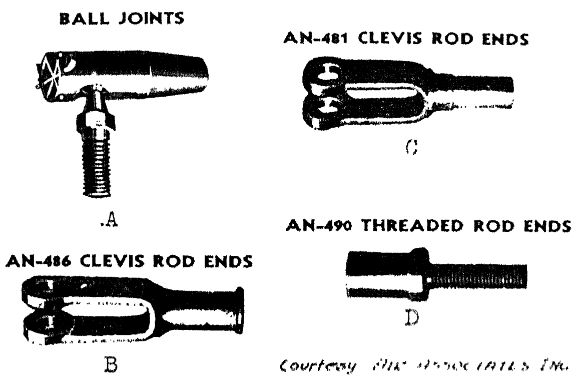


Fig. III

The tubes are made of light gage steel, dural, or aluminum, and are sometimes provided with an adjustment to facilitate obtaining and maintaining the desired amount of movement. One type of adjustment consists simply of a threaded sleeve into which a threaded attachment end is screwed, the threaded sleeve being attached to the push tube. The overall length of the control is increased or decreased by screwing the movable portion in or out. After the correct adjustment is made it is locked by tightening the jam nut. The entire adjustment is similar to that used on an adjustable strut.

Four types of rod or tube ends are shown in Fig. III. Type A, the ball joint, is used where the movement of the control tube and the control arm are not in the same plane. This type of terminal will automatically compensate for plane angle differences up to 15°. Where the crank arm throw and the control tube movement are in the same plane, the terminals B, C and D may be used. Types B and C are designed to be attached to the control arm with a clevis pin while

type D is secured with a cotter pinned nut.

Another type of solid control is used for shut off cocks, valves etc., when the movement must be rotary instead of push-pull. This control is discussed in the section devoted to fuel systems.

The Flexible Control - This control utilizes a sliding member within a tube or casing to transmit movement from the control handle directly to the control arm, thereby eliminating all crank arms, tube guides and bearings. One of the earliest and simplest types of the flexible control is the Bowden cable, shown in Fig. IV. This consists of a solid wire sliding member contained in a spirally wound wire tube or casing. The effectiveness of the Bowden cable depends upon the ability of the solid wire to transmit both a tension and compression stress. The function of the casing is to serve as a continuous guide, preventing the wire from buckling or straightening.

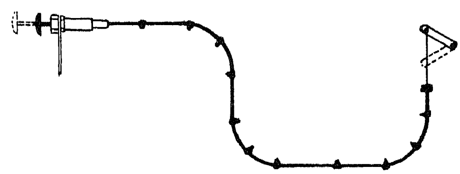


Fig. IV

As would be expected, this control is more easily installed than the solid push-pull tube, however to a great extent its effective operation depends upon careful installation. The outer casing must be anchored in several places, particularly at all bends. There must be no large curves or arcs in an unsupported section of the cable, as the entire unit may buckle or straighten, decreasing effective control movement. The Bowden type of control is also used extensively to operate release and engaging mechanisms where it is necessary to provide control movement in one direction only. The control arm is operated by pulling the wire and is returned to position by spring tension. This eliminates the necessity of using the wire to transmit compression.

Another type of flexible control is shown in Fig. V. The Ahrens control, shown in this illustration, has a more elaborate sliding member, consisting of a dual wound wire. In this the tension, or pull, is transmitted by an aircraft cable inner core and the compression, or push, is taken by a spirally wound wire. The entire sliding member operates inside of a casing similar to that used on the Bowden cable.

A rigid casing is sometimes used for the sliding member housing. The rigid casing, usually of copper tube, provides a somewhat more positive control and is very satisfactory except where it is necessary to have sharp, small radius bends in the line.

Control Handles - Several types of control handles are shown in Fig. VI. Type A is the more conventional style, designed to be used with solid control tubes. This particular model contains three levers, one for the throttle, one for spark and one for the mixture control. The push-pull handle shown in B is used with a flexible

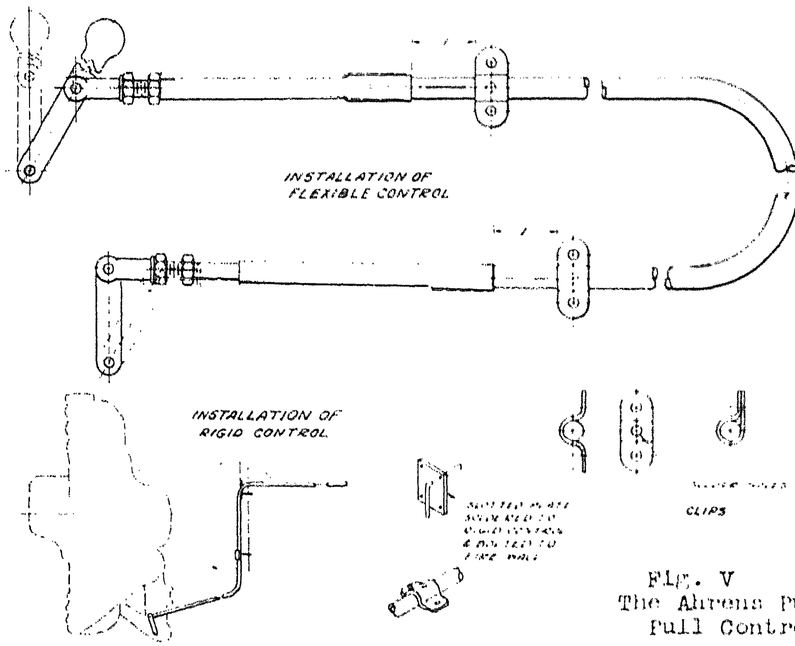


Fig. V
The Ahrens Push-
Pull Control

control and may be used as a throttle control. Another type of push-pull control is shown in view C. This is known as a "vernier" control because, in addition to the rapid coarse setting obtained by pushing or pulling the handle, a fine adjustment may be obtained by turning the knob to the right or left.

The T-handle control shown in D is operated in the conventional manner but after the desired adjustment is obtained it may be locked to prevent further movement. The handle is locked in position by turning it approximately 1/8 turn to the right. It is quickly unlocked for readjustment by turning in the opposite direction.

The button type handles, E, are used mainly for secondary controls although they are sometimes employed for spark, choke and mixture controls on small airplanes.

Courtesy of Air Associates Inc.

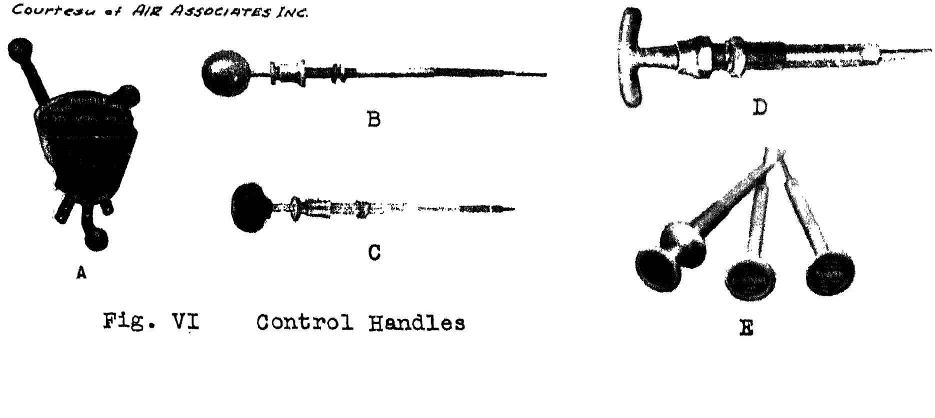


Fig. VI Control Handles

It is impractical as well as unnecessary to attempt to describe the method of operation of all the various types of control handles in use today. However, in general, all controls are arranged so that when they are moved either forward, upward, to the right, or turned in a clockwise direction, the function or operation of the respective accessories is increased or placed in the position of best engine operation. This is a broad and rather vague rule and there are exceptions. The following chart will clarify the meaning.

ACCESSORY OR DEVICE	CONTROL MOVEMENT	ACTION OR EFFECT
Throttle	Forward	Open
Spark		Advance
Mixture		Rich
Choke		Off
Propeller		High pitch
Shutters		Open
Oil heater		Heat off
Ignition switch	Clockwise direction	On
Light switch	Up	On
Control lock	Clockwise direction	Locked
Control vernier		Increased

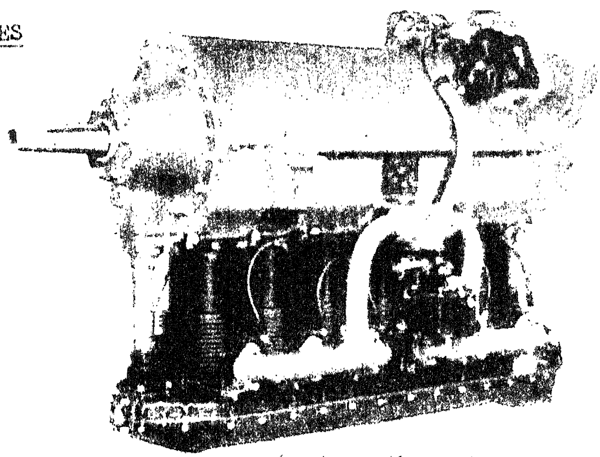
Note: This chart is not complete nor are the specifications true without exception. The correct action of controls should be marked plainly on or near the handles.

IN-LINE ENGINES

In the past there have been many types of water cooled in-line engines used in airplanes, among the most notable of which were the four-cylinder Hall-Scott and the six-cylinder Curtiss K-6 and C-6. For various reasons this type has not enjoyed a lasting popularity. Today we find no liquid cooled in-line engines in production. They have been supplanted by the more modern air cooled in-line engine.

AIR COOLED IN-LINE ENGINES

Fig. I shows a Ranger, six-cylinder, air cooled inverted in-line engine. This is one of the most popular models of this type. The following condensed description of its construction is from the Ranger Engineering Corporation's instruction manual.



Courtesy of Ranger Engineering Corp.

Fig. I

CRANKCASES

"Cast light-metal alloy is used for all crankcase sections. Upper and lower main sections are parted at the crankshaft center line. Both sections are ribbed for seven main bearings and are clamped together by long studs anchored in upper webs and extending entirely through lower webs and crankcase. The parting flanges are held together by short studs. The accessory drive shaft is located in the upper main section. Four engine mounting feet are bolted to the lower main section.

"The front section carries the propeller thrust bearing and the gears for driving the accessory drive shaft and camshaft vertical drive shaft. The rear section carries the drive gears for all accessories.

CRANKSHAFT

"The six-throw, seven-bearing crankshaft is machined from an alloy steel forging. The shaft is statically and dynamically balanced to extremely close limits before being installed in the engine. Main journals and crankpins are hollow and fitted with oil retaining plugs, designed to separate out sludge and foreign material. Crankcheeks are drilled for two-way feeding of oil from main journals to crankpins. The rear end of the shaft carries a standard starter jaw, while the front end has a standard No. 1 taper and key for the propeller hub.

CONNECTING RODS

"Connecting rods are of 'I' section, machined from alloy steel

forgings. Bronze backed bearing shells are used for the main connecting rod bearings, while bronze bushings are used in the piston pin end of the rods.

PISTONS, PINS AND RINGS

"Full trunk type pistons of aluminum alloy are used, ribbed for strength and cooling. Three compression rings are fitted between the piston pin and piston head, and one oil scraper ring at the bottom of the skirt. Piston pins are of heat-treated alloy steel, hardened and ground. The pins are full floating and are retained by snap rings in the pistons.

CYLINDERS

"Cylinder heads are cast aluminum alloy with integral fins. They have machined hemispherical combustion chambers, and are screwed and shrunk on the barrels. Aluminum-bronze valve seats, one intake and one exhaust per cylinder, are shrunk into the heads, and two spark plug inserts are shrunk and screwed in and pinned.

"Cylinder barrels are machined from steel forgings, the fins being integral. The skirts project into the crankcase, and each barrel is secured to the lower half of the crankcase by eight hold-down studs.

VALVES

"One intake and one exhaust valve are used per cylinder. These are inclined to the cylinder axis and are both of the tulip type. They are made of forged alloy steel. Two concentric helical springs are fitted to each valve. Exhaust ports open downward and outward at an angle of thirty degrees with the cylinder axis, intake ports opening outward at an angle of ninety degrees.

VALVE OPERATING MECHANISM

"The camshaft is a heat-treated alloy steel forging, carried in a housing which bolts directly to the cylinder heads. Housing and cover are of light-metal alloy. The camshaft is supported on eight bearings, one located at each end of the shaft and one adjacent to each of the six pairs of cams. It is driven from a vertical shaft which takes its drive from the front end of the crankshaft. The valves are operated by rocker arms which are provided with crowned-roller cam followers and ball type adjusting screws. The end of the adjusting screw is cupped and fitted with a steel ball, the latter having a flat face which provides a large area of contact with the valve stem. From the hollow camshaft, pressure oil is fed directly to the camshaft bearings. Holes drilled in the camshaft between each pair of cams supply a spray of oil to rocker arms, cam followers and adjusting screws.

ACCESSORY DRIVES

"Protection of accessories from camshaft torsional vibration and shock loading is furnished by the drive design, consisting of a

long, hollow, flexible shaft located in the top of the crankcase upper section. This shaft transmits the drive from the propeller end of the engine to the accessory drives in the rear section and completely isolates them from any detrimental vibrations. The accessory drive shaft is carried in seven bearings in the crankcase webs and acts as a header for distribution of oil to main bearings and front end of engine.

LUBRICATION

"The lubrication system is of the pressure type with dry crankcase. A pressure pump with filter, located on the crankcase rear section, circulates oil through hollow engine shafts and cast-in passages, there being no external pressure oil pipes on the engine.

"Part of the oil from the pump is fed to the accessory drives in the rear section, the main supply entering the accessory shaft which distributes it to crankshaft bearings and connecting rods. From the front end of this shaft oil is carried to all drives in the nose section and into the camshaft vertical drive shaft. Thence the oil flows into the camshaft, which distributes it to camshaft bearings under pressure, and to rocker arms and valve stems by spray from holes drilled in the camshaft. Cylinder walls and piston pins are lubricated by oil thrown from the main and connecting rod bearings.

"Excess oil drains from the crankcase to the camshaft housing through the housing for the camshaft vertical drive shaft at the front, or through a duct at the rear of the engine. All oil, after performing its lubricating function, collects in the camshaft housing. A double-suction scavenge pump, located at the rear of the camshaft housing, is arranged to take oil from either end and return it to the supply tank, first passing it through two finger strainers.

INDUCTION SYSTEM

"The updraft carburetor is supported on a bracket bolted to the crankcase on the left side between cylinders 3 and 4. A tee fitting, equipped with a hotspot, connects the carburetor with two pipes leading to the two manifolds, each of which supplies three cylinders.

IGNITION SYSTEM

"Two magnetos are mounted on the upper crankcase section at the rear. Each supplies current to one of the two sets of spark plugs, thus forming a true dual ignition system.

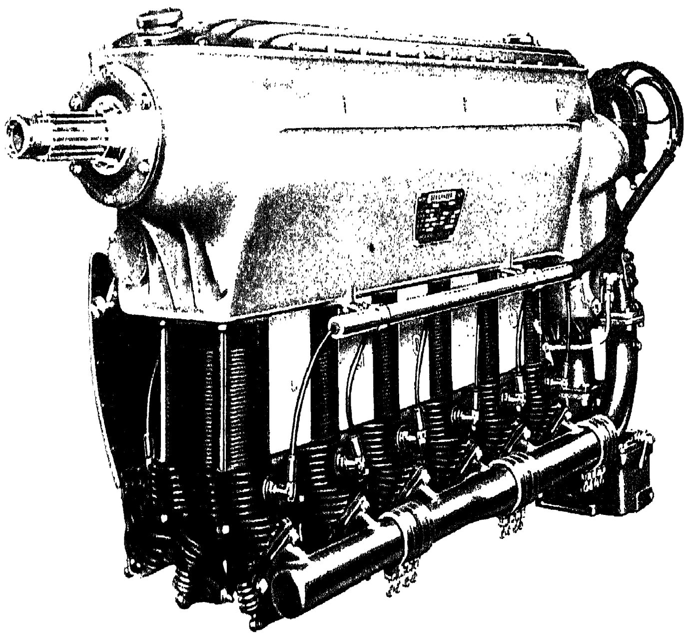
ACCESSORIES

"Standard drives are provided for all accessories, and standard mounting pads or connections are located at convenient points on the crankcase rear section.

MENASCO ENGINES

Another popular type of air cooled in-line engines is the Menasco, illustrated in Fig. II. In this engine the valves are operated

by push rods instead of an overhead camshaft, as in the Ranger. The conventional cylinder hold-down is replaced by 4 long studs extending from the crankcase through some of the cooling fins to a point near the top of the cylinder. This feature makes it more convenient to remove cylinders, as the hold-down nuts are within easy reach. In most other respects the construction of this engine does not differ radically from the Ranger.



200 H.P. MENASCO

Fig. II

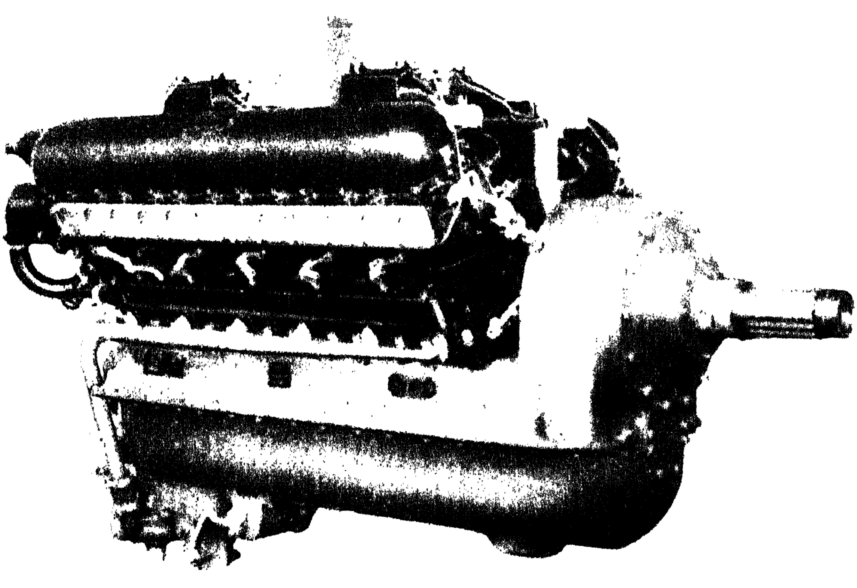
VEE ENGINES

LIQUID COOLED VEE ENGINES

The Curtiss Conqueror engine is a typical example of liquid cooled Vee type engines. The term liquid cooled is used in preference to "water cooled" because most modern aircraft engines of this type use a chemical coolant such as "Prestone." In many ways chemical cooling, or high temperature cooling as it is sometimes called, is superior to water cooling. With the aid of chemical cooling it is possible to control the temperature of the engine and still allow it to run hotter than is possible when using water. Water turns to steam at 212° F., therefore the temperature of a water cooled engine cannot be controlled above this point. Using a chemical coolant it is possible to permit the engine temperature to run as high as 350°. Note: A mixture of one part ethylene to one part of di-ethylene-glycol, which is frequently used as a chemical coolant, has a freezing point of -50° and boils at 397°.

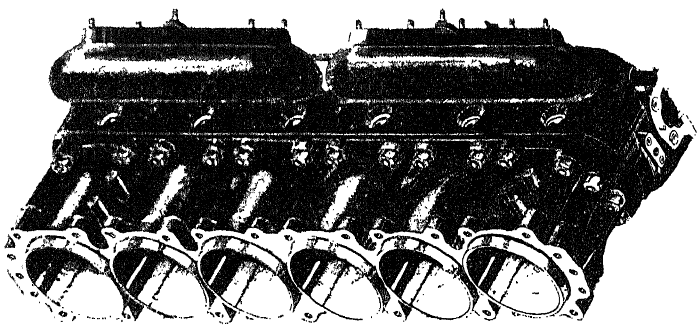
Each row of cylinders is known as a bank. The cylinders in the Curtiss Conqueror are not individual cylinders but are united in what is called a cylinder block, with one bank of cylinders in each block. Some engines have only three cylinders in a block, thus it would take two cylinder blocks to make a bank of six cylinders.

Cylinder Construction - Fig. II shows the construction of the Curtiss Conqueror cylinder block. The cylinder sleeves are made of



CURTISS CONQUEROR ENGINE
(Geared Drive—Three-Quarter Front View)

forged steel and are screwed and shrunk into a cast aluminum alloy head. The aluminum head casting contains the valve seats, valve stem guides, spark plug parts, and provides support for the camshafts and cam followers. A cast aluminum alloy water jacket is placed over the individual cylinder sleeves. This water jacket is sealed by gaskets



Curtiss Conqueror Cylinder Block
Fig. II

at each end so that the cooling liquid, which circulates between the water jacket and the cylinder sleeve, will not leak out. Cylinders which are cooled in this manner are referred to as wet sleeve cylinders.

Valve Operating Mechanism - There are four valves in each cylinder, two intake and two exhaust. The valves are operated in pairs by a tee-shaped cam follower which is depressed by the cam lobes on the camshaft. As the cam lobes rotate and come in contact with the cam followers there is a downward and also a side thrust put on the cam followers. This side thrust is not transmitted to the valves but is absorbed by the cam follower guide which operates on a bushing screwed into the cylinder head block.

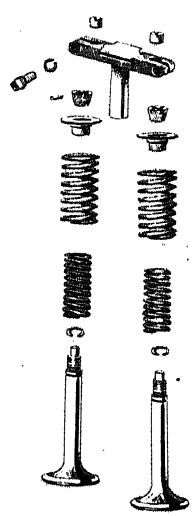
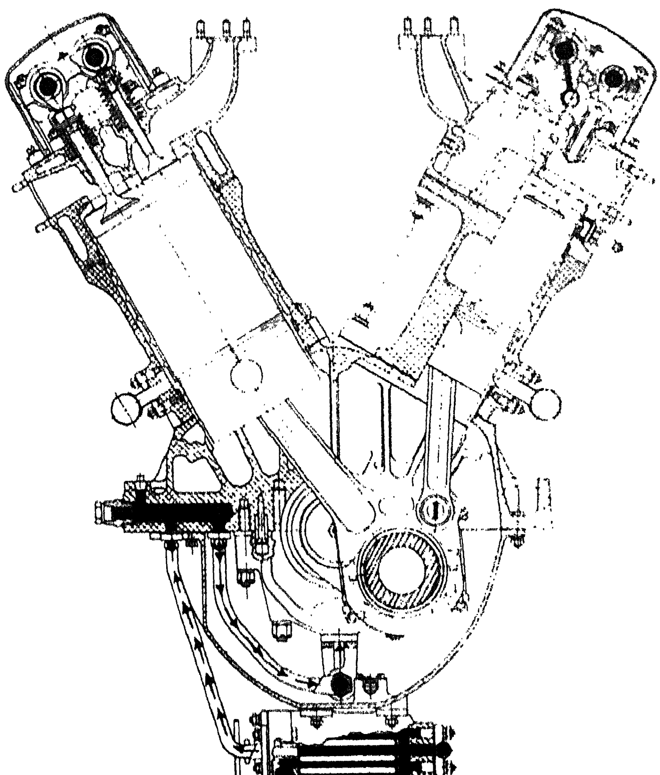


Fig. III

Fig. III shows a pair of valves and the tee-shaped cam follower. The valve clearance is adjusted by means of adjusting screws which are threaded into the split ends of the cam follower. Valve tappet clearance is increased by turning the adjusting screws in the loosening direction and decreased by turning in the tightening direction. After the correct clearance is found the adjustment may bé locked by tightening the lock screw, pinching the split ends of the cam follower together.

The Curtiss Conqueror engine has two camshafts on each cylinder bank, one for operating the exhaust valves and one the intake, as in Fig. IV. Each camshaft has a gear on the end which meshes with an idler gear on the timing gear stub shaft, therefore it is necessary to time each camshaft to the idler gear. The idler gear is driven by a bevel gear meshed with a bevel gear on the tower shaft. With the exception of the dual camshafts, the overhead camshaft operating mechanism of this engine is similar to those on in-line engines.



CURTISS CONQUEROR

Cross section showing lubrication and valve mechanism

Fig. IV

Crankshaft Assembly - One type of crankshaft used in Curtiss Conqueror engines is shown in Fig. V. It will be noticed that this crankshaft is of conventional design and has removable counterbalances on each throw. However, this crankshaft does differ from the conventional in one respect. It has 8 main bearings, or journals, instead of 7. The thrust bearing is a deep row, radial, annular ball bearing which is fastened between the first and second main journal on the propeller end of the crankshaft.

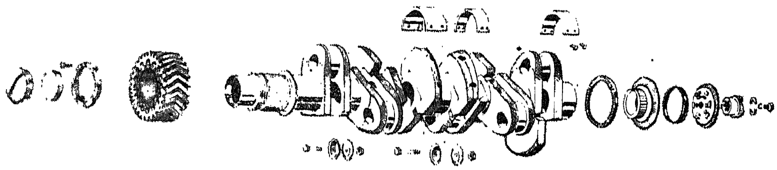


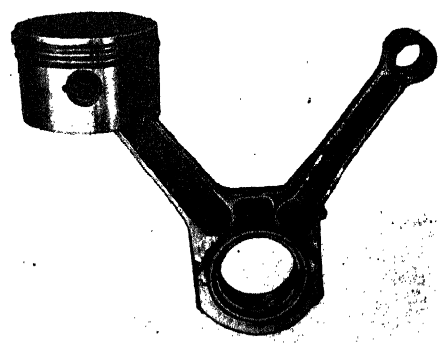
Fig. V

Crankcase Construction - The crankcase of the Curtiss Conqueror is made in two sections. Both sections, the upper and the lower, are made of cast aluminum alloy. The upper section of the crankcase contains integral ribbed reinforcements to hold the eight main bearings. There are two decks at 30° to the vertical plane which form the base for the cylinder blocks. The upper section also carries the engine mounting lugs.

The lower section of the crankcase, called the oil pan, contains two low points, or oil sumps. One of these oil sumps contains the oil pump and strainer.

Piston and Connecting Rod Assembly - The pistons are made of forged aluminum alloy and are constructed with a concave head. The concave head is designed so that it will form one-half of an oval shaped combustion chamber. It is claimed that the power from an explosion is more evenly distributed over the entire piston head when a concave head is used. In other respects the pistons used are of conventional type.

The forged steel connecting rods are of the master and articulated rod type shown in Fig. VI. Each rod is forged into an H section and has bronze wrist pin bearings which are pressed into the rods. The main bearing is steel backed lead bronze and is lubricated by a pressure oil supply from the crankshaft journal.



Connecting Rod Assembly
Fig. VI

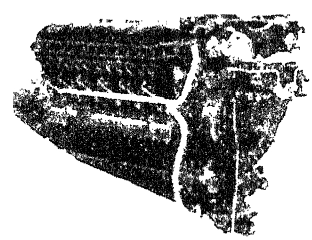
Lubrication System - The Curtiss Conqueror engine uses the dry sump pressure feed lubrication. The oil from the oil tank enters the pressure pump located in the oil pan. The pressure pump forces the

oil through the hollow crankshaft. Each of the journals is drilled to permit the oil to escape from the crankshaft. The connecting rod and wrist pin bearings are lubricated by pressure from the crankshaft journals Nos. 2, 3, 4, 5, 6 and 7. The timing gears and the overhead valve mechanism are lubricated by the oil forced through drilled passages from the rear crankshaft journal. The return oil from the overhead cam mechanism drains back to the sump through the tower shaft housings at the rear of the engine and through external oil lines at the front.

The pressure and scavenger oil pumps are of the conventional gear type. The oil pressure strainer is so designed that should it become clogged the oil is by-passed around the strainer. This feature eliminates the possibility of a clogged strainer stopping the flow of oil to the engine.

While the Curtiss Conqueror is no longer in production there are still many of these engines in use. Furthermore, in construction they are so typical of many Vee engines that have been built that they were selected to illustrate the type.

Two types of liquid cooled Vee engines that are manufactured today are the Allison and the Aero-F. The Allison engine is rated at 1,000 h.p. at 2600 r.p.m. It is a large military engine which has received much favorable attention. In construction it is similar to the Curtiss Conqueror but differs in minor details such as the use of forked and blade type connecting rods, the location and drive of the supercharger and various other accessories.



Allison Liquid Cooled Vee
Type Engine
Fig. VII

The Aero-F is an 85 h.p. eight-cylinder, water cooled Vee engine. It is a converted model V-8 Ford automobile engine. The crankcase is of cast magnesium and the crankshaft is of cast alloy steel. The cylinder blocks are made of cast iron. The engine is of the L-head type, which means that the combustion chamber is extended to one side of the cylinder barrel and contains in this extension both the intake and the exhaust valves.

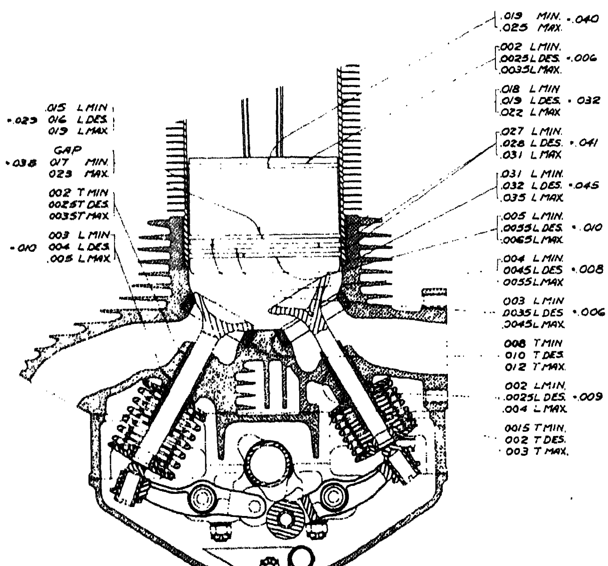
AIR COOLED VEE ENGINES

The Ranger Engineering Corporation manufactures several models of air cooled Vee type engines. These do not differ greatly in construction from the conventional. The cylinders are made individually, using a steel cylinder barrel with integrally machined cooling fins. The cast aluminum cylinder heads are screwed and shrunk on. The valves are operated by short rocker arms which, in turn, are actuated by a single camshaft mounted directly above the combustion chamber. See Fig. I. The camshafts are driven by a tower shaft geared to the crankshaft.

The crankshaft is of the conventional six-cylinder type, having seven main bearings and six throws. The crankcase is of cast aluminum alloy made in two sections, parting on the crankshaft center line. It is held together with two studs extending through the case at each bearing. The nose section contains gears for driving an accessory shaft and the tower shafts. The tower shaft is a vertical shaft geared between the crankshaft and the camshaft. It also houses the thrust bearing. On the geared-drive models the nose section is constructed of two aluminum alloy castings forming a unit which contains, in addition to the above, the reduction gear.

The connecting rods are of forked and blade type forged steel, having either bronze-backed babbitt or steel-backed cadmium-silver bearings. The pistons are of cast aluminum with integral rib reinforcings. There are three compression rings on each piston and one oil ring.

The lubrication system is of the pressure type, dry sump crankcase. A pressure pump with filters, located on a crankcase rear section, circulates oil through hollow engine shafts and cast-in passages to all important points, including the valve actuating mechanism. Cylinder walls and piston pins are lubricated by oil thrown from the main and connecting rod bearings. Excess oil drains from the crankcase to the camshaft housings, through the tower shaft housings, or through the ducts at the rear of the engine. A double suction scavenger pump, located at the rear of each camshaft housing is arranged to take oil from either end and return it to the supply tank.



Cross Section of Ranger Cylinder, Showing Valve Mechanism
Fig. I

HORIZONTALLY OPPOSED ENGINES

The most popular engines for light sport planes are of the horizontally opposed type, as they are dependable, sufficiently powerful, yet light and economical. Naturally, simplicity is the keynote of small engine design and construction. Moving parts have been reduced to a minimum in order to decrease weight and increase dependability. Nearly all of these engines of 40 h.p. or under are provided with only single ignition.

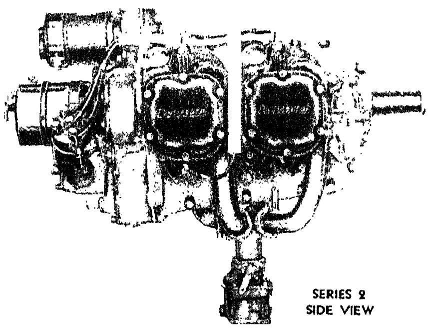


Fig. I

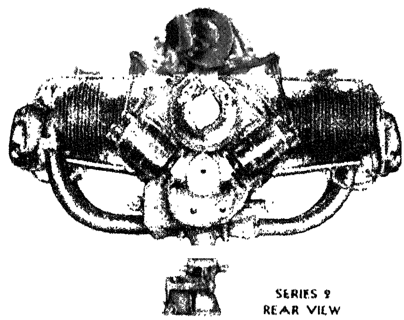


Fig. II

Courtesy CONTINENTAL MOTORS CORP.

Figures I and II show the 50 h.p. four-cylinder, horizontally opposed Continental A-50. This engine is one of the most powerful of its class and incorporates many accessories not usually found on small engines. The optional equipment includes a fuel pump, scavenger oil pump, electric starter, generator, radio shielding and an additional magneto, or battery ignition system, to provide dual ignition.

The Continental A-50 engine illustrated here is provided with dual battery ignition and has individually forged steel cylinders with aluminum alloy cylinder heads which are shrunk and screwed onto the barrels. The entire cylinder is finned for air cooling. The overhead valves are actuated by pushrods which are enclosed in oil-tight housings. The rocker arms are pressure lubricated and the entire assembly is enclosed by full rocker box covers. Hydraulic tappets, which are controlled by the engine oil pressure, eliminate the necessity for making frequent valve adjustments and automatically compensate for expansion of the valve mechanism. The dry sump crankcase is a two-piece aluminum alloy casting fastened together at a vertical lengthwise plane through the crankshaft. Lubrication is assured by a single gear-type pressure pump and gravity scavenging.

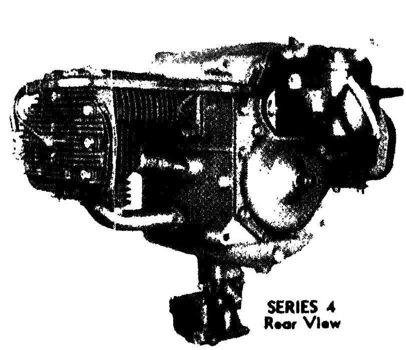


Fig. III

Fig. III shows the 40 h.p. Continental A-40 on which the L-head type of cylinder construction is used. The cylinders are cast in pairs similar to the cylinder banks

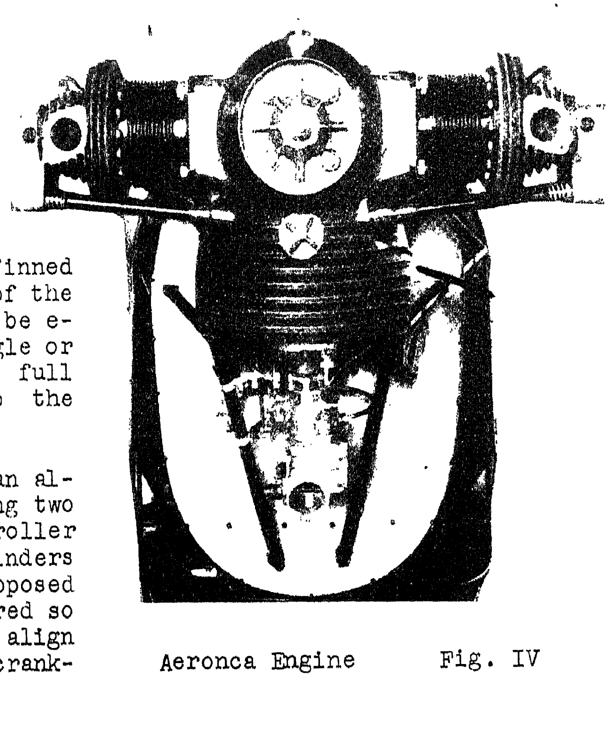
found on Vee type engines. The valves are operated by short tappets between the camshaft and the valve stem ends. Correct valve clearance is secured by means of a tappet adjustment similar to that used on many automobile engines. By loosening the tappet lock nut the tappet adjusting screw may be moved in or out until the proper clearance, or opening between the tappet and valve stem, is secured. The tappet lock nut prevents the adjustment from changing while the engine is in operation. This engine uses a one-piece aluminum alloy wet sump crankcase, and is pressure lubricated by a single vane type pressure pump.

A four throw, one-piece forged alloy steel crankshaft, drilled for pressure lubrication, is used on these engines. The Continental A-50 has three steel-backed cadmium main bearings and the A-40 engine has two lead-bronze main bearings. The connecting rods are of conventional split crankpin bearing type, having either steel-backed cadmium or lead-bronze bearing shells. The aluminum alloy pistons are of the full trunk type.

There are several other four-cylinder horizontally opposed light engines manufactured, but their construction is similar to that of the Continental and for this reason they will not be mentioned here.

The Aeronca is a popular example of a two-cylinder horizontally opposed engine. As will be seen in Fig. IV, this is an air cooled engine, using the overhead valve type of cylinder. The one-piece crankcase is of the wet sump type and finned to increase air cooling of the oil. Aeronca engines may be equipped with either single or dual ignition and have full pressure lubrication to the valve mechanism.

The crankshaft is an alloy steel forging, having two throws and it runs on roller main bearings. The cylinders are not diametrically opposed but are slightly staggered so the connecting rods may align with their respective crankshaft throws.

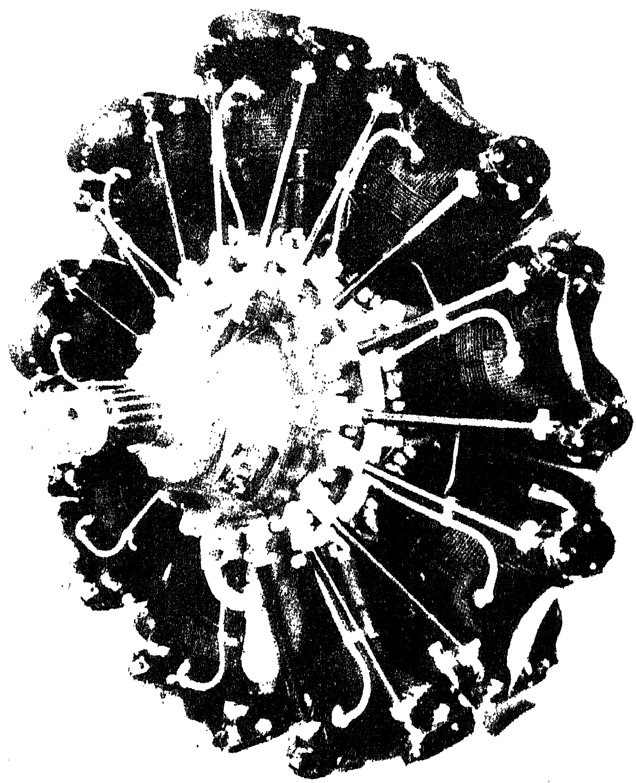


Aeronca Engine Fig. IV

RADIAL ENGINES

Radial engines differ from all other types in that their cylinders are arranged in a plane perpendicular to the centerline of the crankshaft. This type of construction is particularly well suited to air cooled engines as each cylinder receives approximately an equal share of cooling air. There are many types of radial engines, ranging from three cylinders to nine or more cylinders; however the most common type for the larger engines has nine cylinders.

Fig. I shows a three-quarters front view of a 1,000 h.p. Wright Cyclone. This illustrates the stamped, sheet metal deflectors between and above each cylinder. These deflectors, or baffles, serve to direct the air around the cylinder, thus assuring pressure air cooling for the rear of the cylinder.



1,000 H.P. Wright Cyclone

Fig. I

Fig. II shows a rear view of the 550 h.p. Pratt & Whitney Wasp. This view further illustrates the construction of baffles.

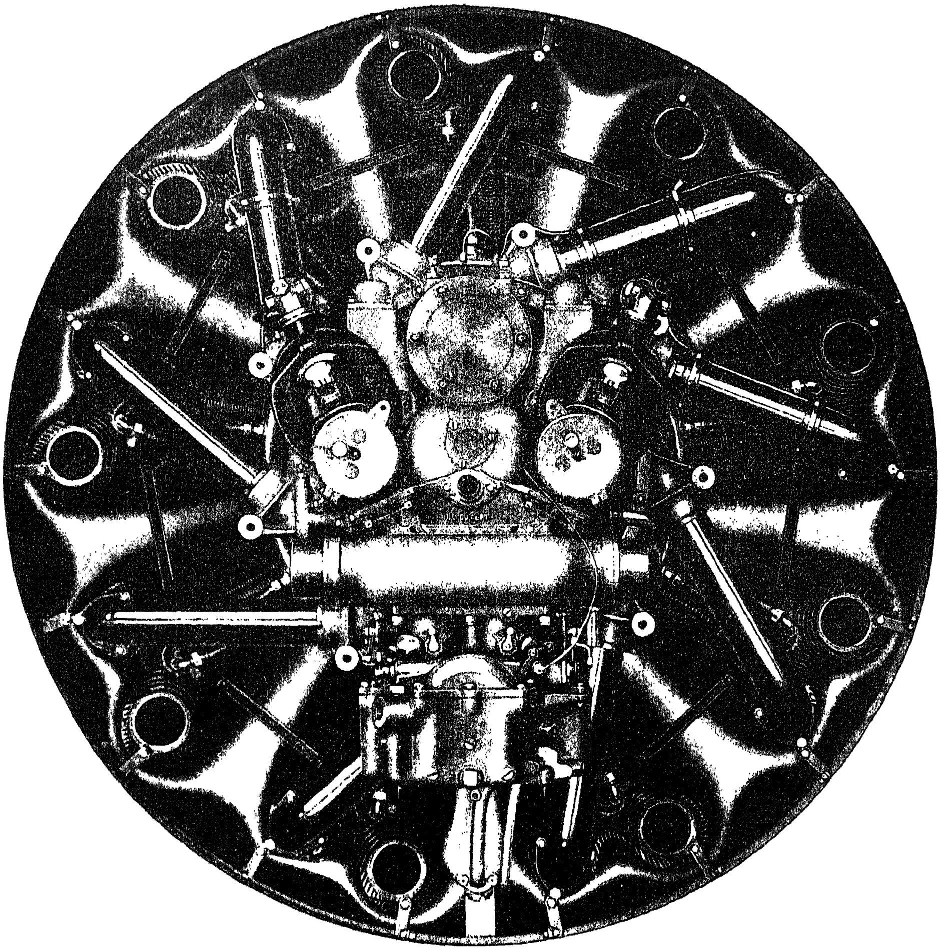


Fig. II

Cylinder Construction - Radial engines use individual cylinders. The cylinder barrels are made of steel and are usually screwed and shrunk into a cast aluminum alloy head. In some of the smaller radial engines, such as the Kinner, the barrels are bolted to the head. The machined steel cylinder barrels are made with a long skirt which extends into the crankcase. As in the inverted engines, this feature prevents the crankcase oil from running down into the lower cylinders. In order to save weight and provide better cooling the cylinder barrels have very thin walls, usually about 1/8" thick, yet these walls must be strong enough to meet the engine requirements.

For this reason the very best grade of steel obtainable is used in their construction. A special type of steel called "nitralloy" is used by the Wright Aeronautical Corp.

The cylinder heads are made of cast aluminum alloy and are finned for better cooling. The head contains the exhaust and intake ports, spark plug ports, and the rocker boxes. Some of the smaller engines have removable rocker boxes. The valve guides are of bronze and are pressed and shrunk into the head. The valve seat inserts are of bronze and are pressed and shrunk into place. Some of the larger engines are using stellite-faced valve inserts. Fig. III shows a typical Pratt & Whitney Wasp cylinder. In this cylinder it will be noticed that the exhaust port has a shrunk-in stainless steel liner which is designed to permit the exhaust stack to be inserted inside the liner and secured by a single stud. Note: The two cables extending from the spark plug base are for a thermo-couple connection.

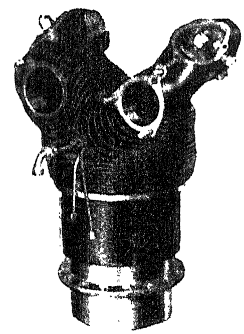


Fig. III

Valve Operating Mechanism - Most radial engines have a cam ring instead of the conventional camshaft. The cam ring in nine-cylinder engines usually has four lobes to operate the intake valves and four lobes to operate the exhaust valves. If provided with four lobes the ring is geared to the crankshaft so that it turns at 1/8 crankshaft speed, or so that the valves open only once for every two revolutions of the crankshaft, as explained in the previous chapter. Fig. IV shows the cam gear arrangement on a Wasp engine. The gear, a, is keyed to the crankshaft and drives gear b. Gear b turns the idler shaft, c, to the rear of which is attached a smaller gear. This small gear meshes with the internal teeth on the cam ring, d. As the cam ring rotates the cam lobes, e, force the cam followers, f, upward. The cam followers transmit this thrust through a push rod to one end of a rocker arm mounted on top of the cylinder. The other end of the rocker arm comes in direct contact with the valve stem, thus forcing the valve open. The valve springs close the valve when the cam follower rolls off the cam lobe. The valve clearance, or the space between the rocker arm roller or tapper and the end of the valve stem, is adjusted by means of an adjusting screw in the rocker arm. The clearance is increased or decreased by loos-

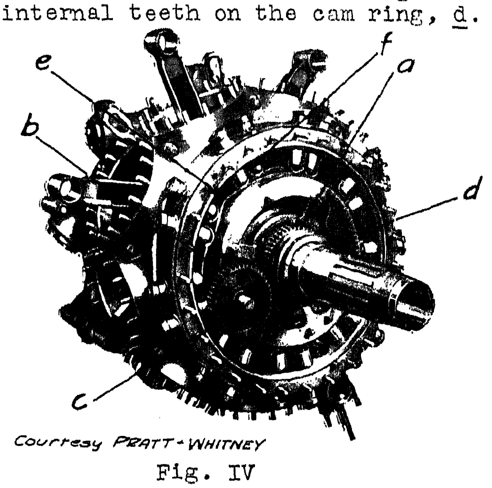
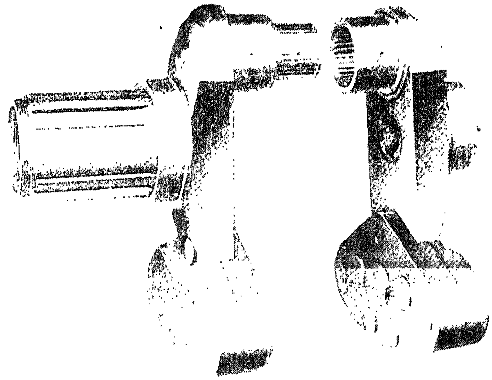


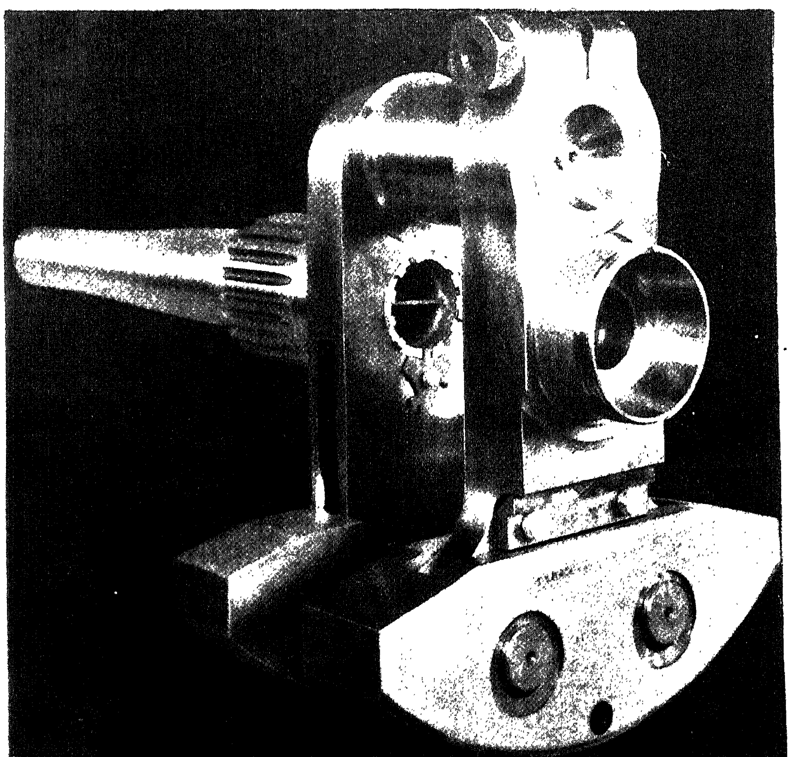
Fig. IV

ening or tightening the adjusting screw. The adjustment is locked either by a lock screw or by a jam nut.

Crankshaft Construction - Most radial engines use a two-piece, single throw, counter-balanced crankshaft made of chrome-nickel steel. Some of the small engines, such as the Warner and Rearwin Le Blonds, use a single-piece drop forged crankshaft. Fig. V shows the two-piece crankshaft used on Pratt & Whitney Wasp engines. The rear section of the shaft telescopes into the front section and is held in angular position by splines. A through bolt holds the sections together. Most engine manufacturers use a rigid type of counter-balance similar to the type



Wasp Crankshaft
Fig. V



Cyclone Crankshaft Fig. VI

shown in Fig. V. However, the Wright Aeronautical Corporation uses a semi-floating counter-weight, illustrated in Fig. VI. This device is called a dynamic dampener and is best explained by the following excerpt from the manufacturer's description.

"Tho general appearance of the dynamic damper, as may be seen from the illustration (Fig. VI) ,does not differ greatly from the conventional counterweight. It is extremely simple and rugged in construction. It is entirely self-contained and introduces no complications that can in any way adversely affect engine operation. It is, in principle, a pendulum counterweight which is mounted on the crankshaft in place of the conventional rigidly mounted counterweight; the pendulous mass being free to oscillate in a restricted arc and in the plane of rotation of the counterweight. When disturbed, the restoring force and the frequency of a given pendulum so mounted is determined by the acceleration due to the centrifugal force of rotation of the counterweight. The magnitude of the acceleration is in turn determined by the speed of the rotation of the crankshaft. Hence, the frequency of any given pendulous mass so mounted will bear a fixed ratio to the speed of rotation of the crankshaft.

"In the case of the Cyclone engine the mass and dimensions of the pendulous weight are of such values that the natural period of oscillation is four and one-half times crankshaft speed, which equals the frequency of explosion impulses. In operation the pendulous weight is of such dimensions and so mounted that it oscillates at explosion frequency but out of phase with the explosion impulses, and thus applies a counter-torque to the crankshaft which balances out the periodic torque fluctuations arising from the explosion impulses, which explosion impulses cause torsional vibration in any conventional rigid crankshaft system.

"Stops are provided to limit the motion of the counterweight during acceleration or deceleration of the engine. These stops are so arranged that they permit a motion considerably in excess of that required to completely damp the torsional vibration at any speed. During normal operation, therefore, the counterweight never strikes the stops.

"The dynamic damper on the other hand is virtually frictionless and dissipates essentially no energy by friction. It acts by introducing a balancing force which is opposite in direction and equal in magnitude to the disturbing force at all speeds. By reason of this action, the dynamic damper has the potential ability to reduce crankshaft torsional vibration to zero.

"Service experience on several of the major airlines has indicated that in addition to accomplishing its primary object of reducing stresses in the crankshaft, the dynamic damper has reduced fatigue effects in propeller blades, and has markedly reduced wear on the components of controllable propellers."

Crankcase Assembly - Fig. VII shows the relative positions of the six section Wright Cyclone crankcase. The first section, or nose section, carries the cam gear mechanism, cam followers, propeller

speed reduction gear and crankshaft thrust bearing, and is also designed to provide for the installation of a constant speed propeller control. The main section, or power section, is divided into two parts, divided along the centerline of the cylinders, and forms the angle decks for supporting the cylinders. This section encloses the crankshaft throw, connecting rod assembly, crankshaft main bearings and cam gear drive assembly. The next section, called the mounting section, carries the engine mount lugs and forms the front wall for the supercharger section. The supercharger section, which is also called the impeller section or blower section, contains the supercharger and diffuser vanes. The section also houses the drive gears for the accessories and provides mountings for the carburetor, fuel pump and machine gun synchronizers. The rear section, or accessory section, forms the rear crankcase cover plate and houses the accessory drives.

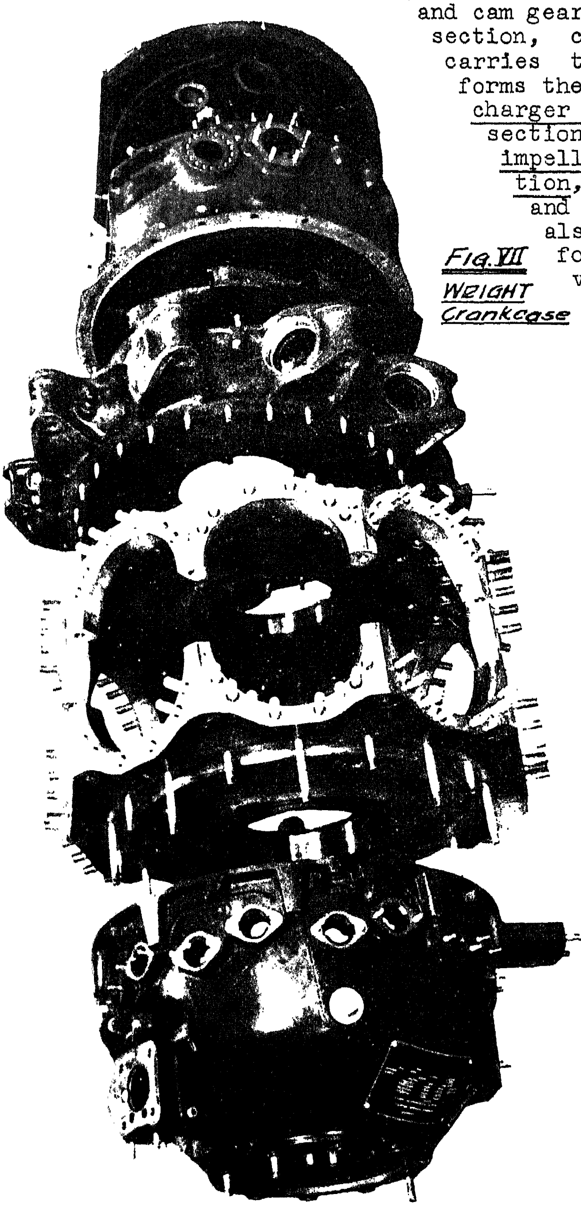


FIG. VII
WEIGHT
Crankcase

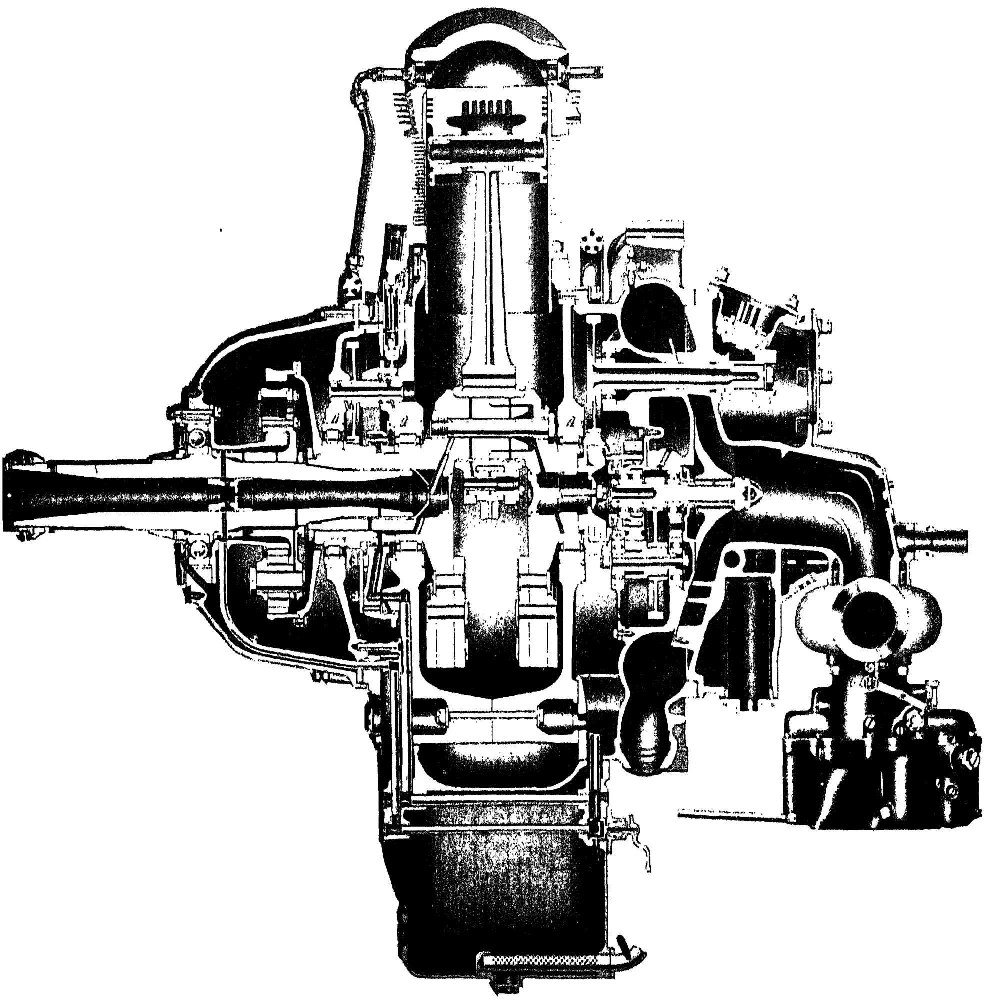
Crankcase sections are often made of forged or cast aluminum alloy. Magnesium alloy is another popular material. Some models of large radial engines use a steel crankcase power section. However, it is unlikely that steel will completely replace aluminum in crankcase construction.

Fig. VIII, a cross section of a Pratt & Whitney Wasp engine, shows not only the crankshaft divisions but plainly illustrates the mechanism carried in each section. In sequence, the divisions are as follows: The first, or nose section, the cam gear section, front power section, rear power section, supercharger section and accessory section.

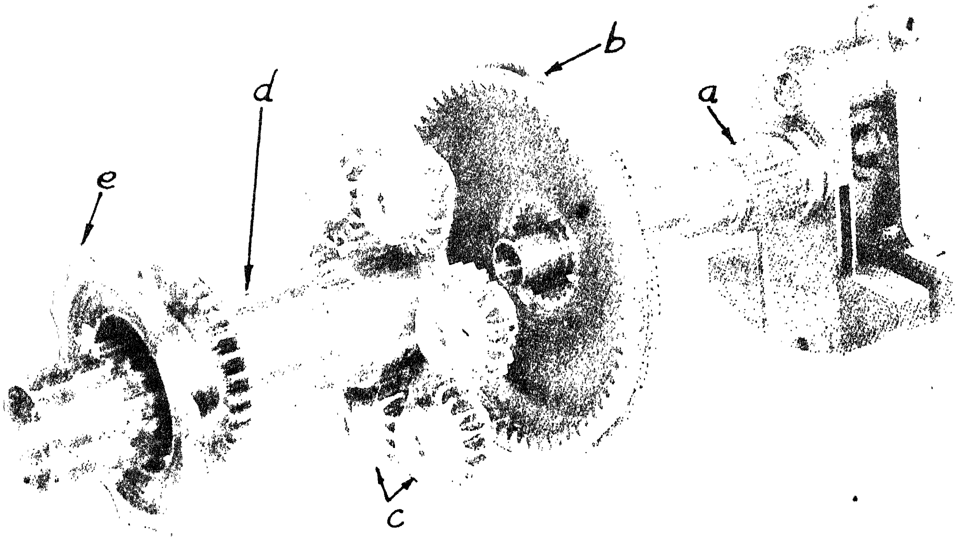
Smaller radial engines do not use a supercharger

therefore the crankcase is very much simplified, usually consisting of only three or four sections. In such cases, the crankcase is divided into the nose section, one or two power sections and the rear section.

Propeller Speed Reduction Gear - Many of the larger radial engines have a reduction gear in the nose section of the crankcase. The purpose of this reduction gear is to allow the engine to turn faster than the propeller. This permits a greater engine output without exceeding an efficient propeller speed.



Cross Section of Pratt & Whitney Wasp
Fig. VIII



WRIGHT CYCLONE REDUCTION GEAR
Fig. IX

Fig. IX shows the propeller speed reduction gear used on Wright Cyclones. The gear ring, b, telescopes over the crankshaft splines, a, and turns with the crankshaft. The small gears, c, which are free to turn on the propeller shaft, d, mesh with the internal teeth on the gear ring, b, and also with the gear plate, e. The gear plate e, is securely fastened to the crankcase. When the crankshaft revolves, turning the gear ring, the small gears are forced to travel around the stationary gear plate. This causes the propeller shaft to rotate in the same direction as does the crankshaft, but at a slower speed. The ratio between the gears regulates the speed of the propeller shaft. The most common reduction ratio is approximately 3 to 2.

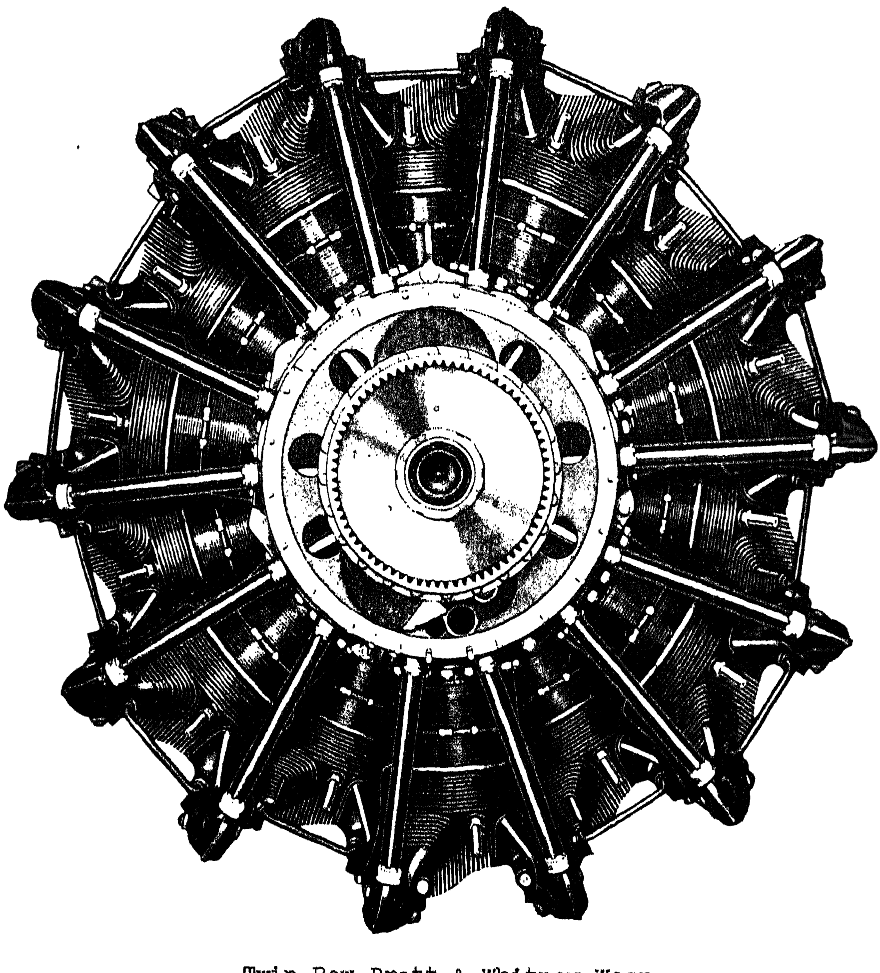
Superchargers - The purpose of a supercharger is to place a positive pressure on the fuel mixture before it enters the cylinder, so that when the intake valve opens a larger quantity of fuel mixture is admitted into the cylinder. This, in effect, increases the compression ratio and results in a more powerful explosion. One of the greatest advantages of a supercharger is that it insures more complete charging of the cylinder when the engine is operating at altitude. Superchargers are discussed more completely in the chapter on Carburetors and Induction Systems.

Piston and Connecting Rod Assembly - The pistons used on radial engines are of conventional type, either of forged or cast aluminum alloy. Some pistons are made with cross ribs, or "waffle plates", on the under side of the head to increase strength and improve cooling.

The connecting rods are of the master and articulated rod type. The master rod has a large crank pin bearing to which all of the

other rods are attached with knuckle pins. The master bearing is made in one piece except on some smaller engines which use a one-piece crankshaft, in which case the master bearing is in two pieces and is clamped together by four stud bolts.

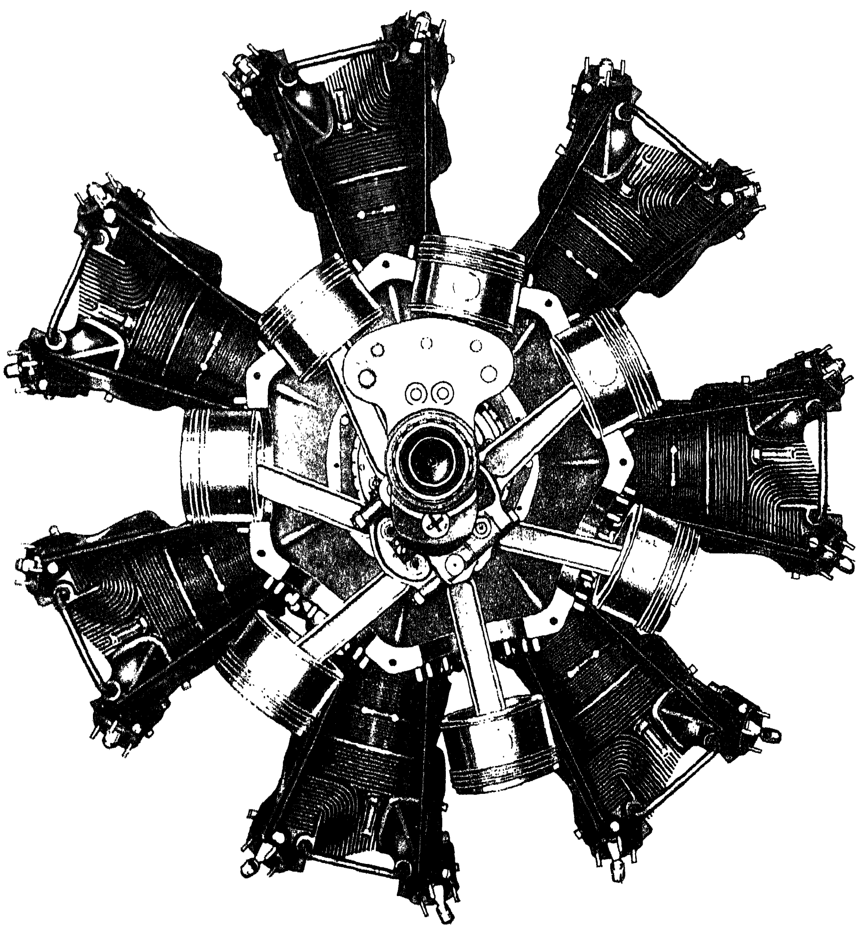
Lubrication - Radial engines are lubricated by a pressure-scavenger system. One or two pressure pumps take the oil from an external tank and force it into the hollow crankshaft. From here the oil is sent to the main bearings, wrist pins, gear drives and also through the pushrods or the pushrod housings to lubricate the rocker arms. Smaller engines do not have pressure lubrication to the rocker arms, in which case the rocker arms are lubricated manually. This is explained in the section "Periodic Check."



Twin Row Pratt & Whitney Wasp
Fig. X

The return oil is not allowed to accumulate in the crankcase but is drained to an oil sump which is lower than the case. From here the oil is returned to an external tank by the return, or scavenger, pump. Oil pumps are explained later.

Twin-Row Radial Engines - These do not differ greatly in general construction from the single-row radial. An external inspection of the engine will show many points of similarity. In fact, many of the parts on the two engines are interchangeable.



Pratt & Whitney Twin-Row Wasp with Front Row of Cylinders Removed
Fig. XI

Fig. X shows a Pratt & Whitney twin-row Wasp with the nose section removed. This view clearly shows the forward cam ring which actuates the valves in the front row of cylinders. There is a second cam ring installed aft of the power section, which operates the valves on the rear row. This means, of course, that each row of cylinders must be timed individually.

Fig. XI shows a front view of a twin-row Wasp in which the front cylinders and the front half of the power section have been removed. It will be seen that only the connecting rods from the front row of cylinders are attached to the throw shown. The rear row connecting rods are attached to the second crankshaft throw, which is diametrically opposite to the first throw.

The crankcase is of the same general construction, with the exception of an additional two sections to accommodate a second row of cylinders. The lubrication system, the exhaust system, the ignition system and the induction system are all similar to those used in the single-row radial, being increased in size to provide for the increased number of cylinders.

CHAPTER 4

TOOLS, EQUIPMENT AND METHODS

One of the surest indications of the ability of an airplane mechanic is his selection, use and care of tools. A good mechanic realizes the importance and value of tools. He knows that good tools are expensive and are not to be abused or carelessly misplaced. He knows enough not to risk lowering the quality of his workmanship by using inferior tools which may fail in an emergency. He will beware of tools that are designed to do a great variety of jobs, such as a device that is proclaimed to be a hammer, axe, screw driver, nail puller, monkey wrench, pinch bar and cork screw, all in one. Yet he knows how to assemble a light, compact flight kit, selecting a few tools that will enable him to make almost any minor adjustment or repair. In short, a good mechanic knows and respects his tools.

It would be difficult to say just which tool is the most important or even which ones are used the most frequently. However, as far as possible, the most common and useful tools will be described first. Special tools, or those that are designed to do specific jobs, are not included here as their use is too limited. If a special tool is required, a description of the tool and its use is usually given by the engine manufacturer.

Diagonal Cutters - It has been said that "a mechanic's best friend is his diagonals", and while it is to be hoped that this is not literally true, it serves to indicate the popularity of this tool. The diagonal is a short-jawed cutter, having blades at a slight angle to the handle, Fig. I. It is used to cut soft wire, and is practically indispensable in removing or applying safety wire. The jaw angle makes it particularly well suited to removing and replacing cotter pins and of course the cutters easily nip cotter pins to the desired length. It is also one of the most convenient tools to use for removing small nails and tacks and to cut soft rivets.

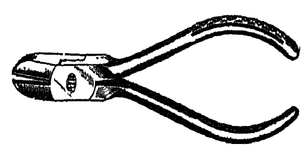
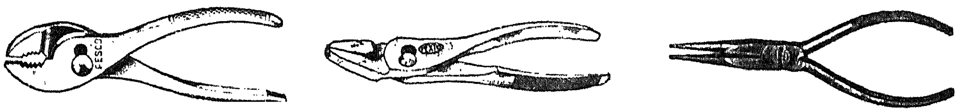


Fig. I
Diagonal Cutters

In an emergency, diagonal cutters have been used for a great many purposes for which they were not designed. They have been used to cut insulation from electrical cables, to cut plywood, serve as tin snips, etc. They are sturdy tools and will stand much abuse. They should not, however, be used to cut spring steel wire or hard rivets, as either of these is likely to damage the cutting edges. When cutting the largest material within the capacity of a diagonal, the back of the jaw and not the point should be used. This reduces the tendency to spring the jaws. Once the jaws are sprung it is difficult or impossible to cut fine wire with the point.

Pliers - There is often a tendency among inexperienced mechanics to use pliers as a universal tool, and indeed it is a great temptation at times to use pliers to tighten a nut or to remove a tube



A B C

Fig. II

Courtesy of Air Associates, Inc.

connection rather than take time to get the correct wrench or tool. This should by all means be avoided, for it is one practice that will not be tolerated by any foreman or supervisor. In addition to the likelihood of the pliers slipping, the teeth on the jaws may fracture the part or round the corners on the nut. A safe rule to follow is never to use pliers as a substitute for a wrench. Fig. II shows three of the most common types of pliers used by the engine mechanic, combination pliers A, thin nose B, and the long nose C. Each of these has a wide range of utility and can hardly be surpassed as an emergency tool. The thin nose pliers are often used for removing or attaching safeties. Long nose pliers are handy in reaching more inaccessible places. They are also used in electrical work, to cut small wire, to serve as tweezers, etc.

Wrenches - As the majority of bolts, nuts and capscrews used on an engine are provided with hexagonal heads, the tools used most frequently in removing and replacing parts are wrenches. There are many types of special wrenches designed for particular fastenings but these are described by the engine manufacturer. The standard wrenches do not differ greatly from those used in other trades, except that wherever possible they are made smaller and lighter. Naturally, to do this and not sacrifice strength it is necessary to use a better grade steel, and for this reason aircraft wrenches often cost much more than other kinds. One of the most popular materials for aircraft wrenches is chrome-vanadium steel. Some wrenches made of this material are almost unbreakable and it is practically impossible to spring the jaws. In fact, some companies unconditionally guarantee their wrenches against destruction.

Fig. III shows a set of typical open end wrenches. As a rule each wrench has two different jaw openings designed respectively to fit nuts of consecutive size. For example, one wrench will fit 1/4" and 5/16" nuts. The next larger wrench in the set fits 5/16" and 3/8" nuts. The wrenches shown here have the jaws at a 15° angle to the handle and while this is about the average, there are some made with a greater or smaller angle. One popular type, the right angle wrench, has jaw openings at 90° to the handle.

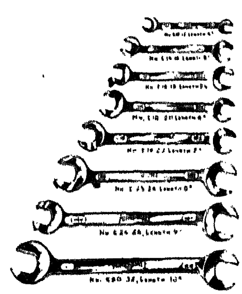
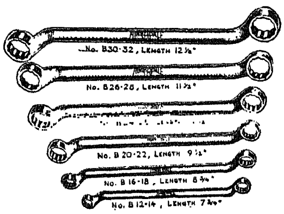


Fig. III

There is very little that can be said about the actual use of a wrench, except to caution against abusive treatment, such as using it for a hammer or a pry bar. Only experience will teach a mechanic

how much to tighten a nut; however, a general rule is to give an additional 1/8 turn after the nut is snug.



Box Socket Wrenches
Fig. IV

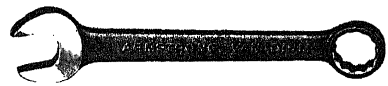
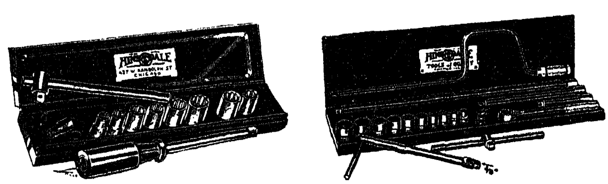


Fig. V

<u>Box Socket Wrenches</u> - A set of box socket wrenches is shown in Fig. IV. <u>These wrenches</u> have closed ends with a six or twelve sided opening in the head for the nut. The main reason for the popularity of these tools is that they can be used more conveniently where space is limited, due to the fact that the head is narrow as compared to the open end wrench. Another reason, in the case of the 12-point type, is that the handle does not have to be swung through as great an arc before a new grip on the nut can be obtained. The relative size of the head of a box socket and of an open end wrench is shown in Fig. V. When a 12-point wrench is placed over a nut, only six of the points grip the nut, thus when working in a limited space the nut may be turned 1/12 of a turn, or 30°, and by returning the wrench to its original position a new grip on the nut can be made, using the second set of six points. The six point wrench must be swung through 60° before a new grip can be taken.

An additional feature of the 12-point wrench is that it can be used on a square nut. For special jobs these wrenches are made with handles of many shapes, such as S curves, offsets, right angles, etc.

<u>Socket Wrenches</u> - There are many kinds of socket sets used by engine mechanics, ranging from small midget sets (Fig. VI-A) to large combination sets (Fig. VI-B) that contain sockets for all the standard nuts from a #6 machine screw to a 3/4" standard nut. Socket wrenches are made to fit larger nuts, but are not, as a rule, included in sets and usually have to be purchased separately. The sockets are usually made of some tough, strong material such as chrome-vanadium steel and have a six or twelve point opening for the nut on one end with a 9/32" or a 3/8" square opening on the other end for the handle. Individual sockets may be obtained to fit various sizes of square or special nuts, and also with a screw driver blade attachment.



A B

Fig. VI

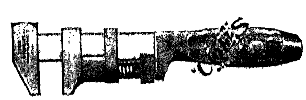
Courtesy of Air Associates Inc.

The utility and convenience of a socket set are greatly augmented by various types of handles, such as the T handle, ratchet handle, screw driver grip handle and a "speeder" handle, the last resembling a carpenter's brace in shape. In addition to these, many socket sets have extension bars of various lengths, and universal joint attachments. With so many accessories available, it is possible to assemble a combination wrench that can do almost any job quickly and easily.

Inasmuch as the handles are interchangeable, it is possible to apply as much leverage to a small nut as to a large one; hence it is more difficult to "feel" when a nut is tight enough with a socket wrench than with an ordinary wrench. For this reason a mechanic should take particular care not to put too much pressure on the smaller sizes of nuts, or damage in the form of stripped threads or a broken bolt may result.

Adjustable Wrenches - Probably the most widely used of the adjustable wrenches is the type shown in Fig. VII, commonly called a "Crescent" wrench. This tool has a spiral screw-worm adjustment in the handle so that the width of the jaws may be varied from zero to the capacity of the tool, which may range anywhere from 1/2" to 1-1/2" or more. It has smooth jaws and is designed to be used as an open end wrench, and is an especially good emergency tool, since one adjustable wrench can be made to serve for several end wrenches. It is practically indispensable for work on a foreign engine or one that has metric nuts, which our standard wrenches will not fit. Naturally, metric wrenches are made for these engines, but there are only a few places where they can be purchased.

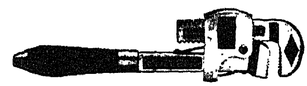
Angle Adjustable Wrench
Fig. VII



Monkey Wrench
Fig. VIII

When using the Crescent wrench it is essential that the jaws be adjusted as tightly as possible on the nut, otherwise the wrench will slip or the jaws will be sprung. Where possible, the wrench should be turned in the direction of its movable jaw, as this reduces the likelihood of breaking the sliding web which holds this jaw. Although these wrenches are quite strong, they will not stand excessive strain, especially at the wide open position.

A monkey wrench is similar to the Crescent wrench but its jaws are at right angles to the handle, as shown in Fig. VIII. The lower jaw moves parallel to the handle to adjust the width of the opening. The monkey wrench is not a popular tool with airplane engine mechanice, however it is sometimes used and is often included in engine tool kits. Its most common use is not on nuts and bolts, but on such parts as covers, strainers, caps, breathers, etc., that have a large square or hexagonal boss for a wrench and do not require much pressure to turn.



Stillson Wrench
Fig. IX

The Stillson wrench, Fig. IX, is primarily a pipe wrench and its use is therefore very limited. It should never be used on nuts or bolts as the toothed jaws will cut into metal. The lower jaw is stationary and the upper, movable jaw is pivoted to the handle in such a manner that it is free to rock back and forth through a small arc. When fitting the wrench to a pipe the jaws should be adjusted so that the pipe fits tightly in the back of the jaws. By pulling the handle forward, or toward the open end of the jaws, the top jaw swings slightly forward, decreasing the jaw opening, thus firmly clamping the pipe between the teeth. It is released from the pipe by turning the handle in the opposite direction.

This wrench is not an engine tool and is not to be used as such, as damage to the part will surely result. It is designed for turning pipes or other round objects where the damage caused by the teeth is of no consequence. If used only for this purpose it will prove to be a valuable addition to any station tool kit.

Torque Wrench - It has long been a problem to know just how much to tighten a nut. Naturally, a mechanic has to rely upon his judgment and "feel", but this method is neither exact nor consistent. While this method is satisfactory for the majority of cases, there are many places on an engine where it is desirable to have a certain uniform tension on the nuts. The new types of torsion wrenches and constant tension wrenches have been developed to replace the guesswork method. These wrenches have either a dial mounted in the handle where the exact tension applied can be read, or they have a friction adjustment which can be set to a predetermined tension so that it is impossible to tighten a nut beyond a certain amount. At present these wrenches are expensive, but are particularly valuable on engines whose manufacturers cooperate by publishing tables of desired bolt tensions.

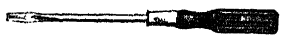
General Use of Wrenches - As wrenches are really the fundamental tools of the engine mechanic, the following suggestions should be studied carefully:

1. Make sure the wrench selected fits the nut exactly.
2. Keep wrenches clean and free from oil, otherwise they may slip, resulting in possible serious damage, both to the parts on which they are used and to the hands of the mechanic.
3. Be very careful about increasing the leverage on a wrench by putting a tube or extension on the handles, especially when tightening a nut, as the increased leverage makes it easy to apply sufficient tension to exert an undue strain on the bolt, resulting in either stripped threads or a broken bolt.
4. Provide some sort of a kit or case for all wrenches and return them to their case at the completion of each job. This may often seem to be an inconvenience, but actually it is a time and trouble saver. It prevents loss, facilitates selection of tools for the next job, and, most important, eliminates the possibility of leaving them on the power plant where they may cause serious damage when the engine is started.

5. Before attempting to loosen a nut, make an effort to determine which way it should be turned. This may seem very elementary, but even experienced mechanics have been observed straining at a nut in the tightening direction in an effort to loosen it.

Screw Drivers - Although it might seem that everyone should be familiar with so commonplace a tool, it is surprising how much ignorance is frequently displayed in the use and care of a screw driver. It is not a tool to be selected and used carelessly, but should be chosen carefully and used intelligently.

A



B

Wood Handle Screw Drivers
Fig. X

There are many types of screw drivers, ranging from the small watchmaker's size to those 24" or more in length. Many are designed for special jobs, or special types of fasteners. However, only the more common types will be discussed here. The standard screw driver, shown in Fig. X-A, is well known and needs no introduction. The cabinet style, Fig. X-B, differs from the standard in that its shank is usually longer and the blade width is the same as the shank diameter. This latter feature makes the cabinet screw driver especially well suited to driving countersunk screws. The electrician's screw driver is supplied in either the standard or cabinet blade type, its particular feature being an insulated handle. The advantage of such a handle, of course, is that electrical connections can be made with less danger of transferring an electrical shock to the user.

Spiral Screw Driver
Fig. XI

A spiral screw driver, such as that shown in Fig. XI, is a great time saver when many screws are to be driven. While this is more a woodworker's tool, it is occasionally handy for the engine mechanic. It consists of a spirally grooved shank, fitted in a hollow handle which is provided with a ratchet device. When the handle is pushed, the blade revolves in either the tightening or the loosening direction, according to the ratchet setting. Pulling the handle back to its original position does not turn the blade, but merely prepares for the next stroke. A third position of the ratchet locks the action so that the screw driver may be used in the conventional manner.

The offset screw driver is used where it is difficult to reach the screws with the regular type of tool. It consists of a short shank, having at each end a blade, which is bent at right angles to the shank. The point of one blade is parallel to the shank and the point of the other is at 90° to the shank. This is a rather awkward tool to use, as it is difficult to exert sufficient down-pressure to hold the blade in the slot and still turn the screw; however, many times it is the only tool that can be used for a particular job.

Although nearly everyone is to some extent familiar with the use of a screw driver, there are a few points which can be emphasized,

the most important being not to allow the blade to slip from the slot, as damage to the screw head or adjacent material will result. To avoid this, three things are necessary. The screw slot must be clean, the blade must fit the slot correctly, and it must be held in position with sufficient force.

Screws that are particularly tight may often be removed by forcing the blade into the slot as tightly as possible, then turning the screw driver shank with a small Stillson wrench, or with good pliers. A small open-end wrench can be used for this purpose if the shank is square. Sometimes "jarring" a screw will make it easier to remove. This is done by holding the screw driver in position and rapping the head of the handle once or twice with a hammer. Utmost caution should be used in this procedure, as there are many places where a jolt such as this might crack or otherwise damage some adjacent part. "Hammering on the handle of a screw driver" is certainly not recommended here, but with the use of a little judgment the method outlined above can be effectively employed with no damage to either the screw driver or the work. A carpenter's brace and screw driver bit may be used to drive large screws, or to remove particularly obstinate ones, as considerably more pressure can be exerted to hold the blade in place and more leverage is available for turning.

A correctly shaped blade is shown in Fig. XII. It will be noticed that the blade taper is not constant from the point to the shank diameter. Instead, the sides of the blade are parallel for a short distance at the point before the taper starts. This gives the blade more bearing surface in the slot than would otherwise be obtained. The point should be flat, of uniform width and at exactly 90° to the shank.

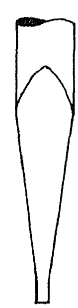
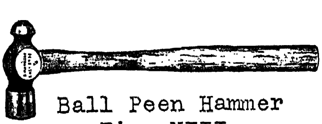


Fig. XII

Hammers - A mechanic's tool kit cannot be considered complete unless it contains at least two or three types of hammers. The most useful of the hard face hammers is the ball peen, or, as it is sometimes called, the machinist's hammer. Ball peen hammers, such as that shown in Fig. XIII, are made with hardened steel faces and fitted with a stout handle of hickory or other hardwood. The three most popular sizes are the six ounce for light work, the twelve ounce for general utility, and the sixteen ounce for heavy work. The use of hammers is too common to be described, however the following safety precautions should be observed at all times.

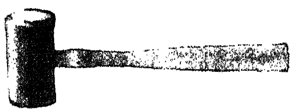
1. Never use a hammer with a cracked handle.
2. Make sure that the head is tight on the handle. If the head appears to be loose, it can be tightened by rapping the butt of the handle sharply on the bench or other wood object. After the head is in place it should be secured by re-setting the wedge in the end of the handle.



Ball Peen Hammer
Fig. XIII

3. Never use a hammer to strike a

hardened metal surface, as there is a possibility of chipping small particles from either the face of the hammer or the material. When possible, place a thin sheet of copper or aluminum on a hardened surface before hammering. This will not reduce the force of the blow to any great extent but will prevent chipping.



Rawhide Mallet
Fig. XIV

Soft-Face Hammer
Fig. XV

Soft-face hammers are used extensively by the mechanic where it is necessary to avoid scarring or denting the material. There are many materials used for the faces, some of which are wood, rawhide, babbitt, copper, and pyralin. As a general rule a wooden mallet does not make a satisfactory soft-face hammer, as the wood is likely to splinter. A closely wound rawhide mallet, such as is shown in Fig. XIV, is very satisfactory where a hammer of this type is needed. This tool will stand a surprising amount of abuse, but must not be used on objects of small diameter, such as bolts, punches, etc., as they will destroy the surface of the face.

A somewhat more elaborate type of soft-face hammer is shown in Fig. XV. A feature of this tool is removable tips which are clamped in the head of the hammer. The tips may be of rawhide, babbitt or copper.

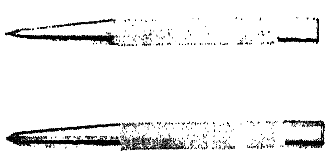


Fig. XVI

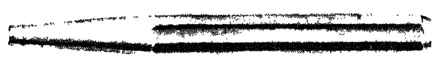


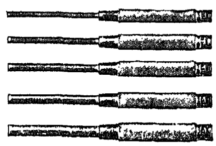
Fig. XVII

Punches - No mechanic's tool kit would be complete without an assortment of the various types of punches. These are simple tools and may be used for a variety of jobs, but it is essential that the mechanic select the correct punch for the job. Some of the more popular types of punches and their uses are described below.

The prick punch, shown in Fig. XVI-A, is used for marking exact points such as the locations for drilled holes, etc. This tool should not be confused with the center punch, Fig. XVI-B, which is heavier and more bluntly pointed, and is used for putting permanent indentations in metal, or for making a starting hole for drilling.

The lining-up, or drift punch, has an evenly tapered shank and a flat point, as illustrated in Fig. XVII. This is used for aligning holes before starting bolts. The drift punch is also used as a general utility tool to transfer the blow of a hammer to a desired

point. If it is necessary to remove a bolt by force, it should be started with a drift punch having a point diameter nearly equal to that of the bolt. A center punch should not be used for this purpose as the sharpened point will act as a wedge and will actually tighten the bolt in the hole. It is customary, when removing a bolt, to strike the exposed end of the bolt directly with the soft face of a hammer. The bolt may then be pulled out from the opposite end; however, if it cannot be pulled it may be driven out with the drift punch and pin punch.



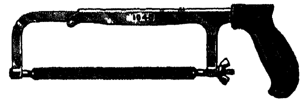
Drive Pin Punches Fig. XVIII

Hollow-Shank Punch
Fig. XIX

Fig. XVIII shows a set of drive pin punches. These tools have a shank of constant diameter and a flat point. They are used to remove pins or bolts, however, they are not designed to withstand as much abuse as a drift punch. If the pin punch is used for starting a bolt or pin, a heavy blow from a hammer may break or bend the shank, therefore this tool should not be used until after the bolt or pin has been removed as far as possible with a drift punch.

A hollow-shank punch, such as that illustrated in Fig. XIX, is very useful for making holes of small diameter in soft gasket material. The point is tapered to a sharp cutting edge in order to produce clean, uniform holes. Where possible, the material to be cut should be placed over the end grain of hardwood as this provides sufficient backing and at the same time protects the cutting edge of the tool.

There are many types of special punches which really come under the classification of special engine tools. Of these, one of the most popular types is the brass faced drift. This is a steel tool designed for such purposes as removing shafts or wrist pins. It is heavy enough to resist damage to itself and is provided with a brass point, or face, which is soft enough not to injure engine parts.



Hack Saw
Fig. XX

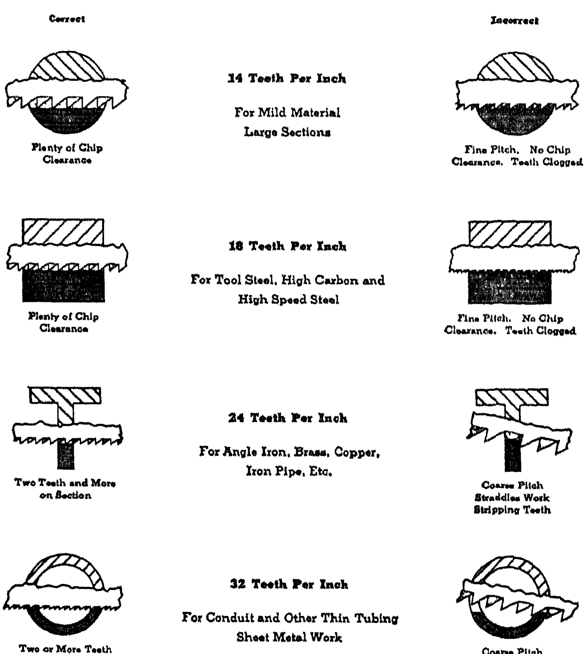
Hack Saws - A standard type of hack saw, consisting of a narrow steel blade held in an open frame, is illustrated in Fig. XX. The blade is removable and when desired can be replaced with one having a different length and a different cut. The hack saw is designed primarily for metal work but can be used with equal success to cut wood, fiber, hard rubber, and many other similar materials. A hack saw may be considered a general utility tool and one to be included as standard equipment in every tool kit. Its uses include sawing bolts, nails, wire, tubing, shafts, bar stock, flat

stock, etc.

To get the best results from using the hack saw for its various jobs, much care should be used in the correct selection of the blade. For general use a 12" blade will give better results than a shorter blade as it permits a longer stroke. It may be necessary, however, to use a shorter blade where space is limited. A blade having 24 teeth to the inch will give good results for general work.

In selecting the proper point blade, it should be remembered that generally speaking, coarse teeth cut faster, but with a fine tooth blade there is much less danger of blade breakage. By referring to the chart in Fig. XXI, the correct blade may be determined quickly. Hack saw blades have rip saw teeth, which are bent outward on opposite sides to give the blade a sawing clearance. Every third tooth is straight to serve as a raker or cleaning tooth.

In assembling a hack saw the blade should be put in the frame with the teeth pointing forward. The blade will not break as easily if it is tightened firmly in the frame. In sawing, the pressure should be applied on the forward stroke and the saw raised slightly on the return stroke to avoid "rounding" the teeth. If space permits each stroke should be made the entire length of the blade, using a slow, even pressure of not over 60 strokes per minute.



Courtesy of L.S. STARRETT CO.

Fig. XXI

Ordinarily, material to be sawed is held in a vise. However, in sawing thin material, a much better job can be done if the material is clamped flat on the bench with the portion to be cut extending beyond the edge. By using a fine tooth blade and holding the saw at a very flat angle to the material, a smooth, straight cut will result.

It is sometimes possible to remove broken studs by sawing a screw driver slot in the broken end of the stud shank and removing with a screw driver. Where it is necessary to do this type of work or where it is desirable to remove considerable metal in a cut, it is often convenient to use a hack saw fitted

with two blades instead of one. This will give a true cut the thickness of the two blades.

In sawing thin wall tubing the teeth of the hack saw will last much longer if the pressure is applied on the back stroke and released on the forward stroke. The same effect may be accomplished by holding the hack saw backwards and sawing as usual.

Soft tubing may be cut without binding the blade or flattening the tube by first inserting a wood dowel of the correct size to fit the tube.

Holes may be cut from the inside of material by drilling a large starting hole, inserting the hack saw blade and re-assembling the saw. The blade may be faced in any one of four directions in reference to the frame, in a manner very similar to the coping saw. For special work a hack saw having a much deeper frame is made. With this saw it is possible to take a wider cut.

MEASURING DEVICES

It is certainly true that a mechanic's work is no more accurate than his measurements. Also, inasmuch as a mechanic is required to make many precision measurements of various kinds, a careful study of the different systems of measure and a knowledge of the various tools and instruments used for this work will reward him by increasing his accuracy and efficiency.

The most popular linear measure in the United States is the English system. The standard measure, a yard, is divided into three feet; a foot is divided into twelve inches; the inch is divided into fractions of halves, quarters, eighths, sixteenths, thirty-seconds, and sixty-fourths. It has been found impractical to divide the inch into smaller fractions than sixty-fourths due to the difficulty and consequent confusion which would arise from working with such fractions as 1/128th, 1/256th, etc. Therefore, for precision measurements, the inch is divided into decimals, or portions of an inch which are divisible by 10. To be specific, an inch is first divided into ten parts (in the decimal division), making each part equal to 1/10th of an inch, which is designated by the written decimal .1" (one tenth), or .100" (one hundred thousandths). The tenth part of an inch is further divided into ten parts, each of which is equal to 1/100th of an inch, and is written .01", or .010" (ten thousandths). By dividing .01" into ten parts the next decimal, one thousandth of an inch, is obtained. One thousandth of an inch, which is written .001", is of course the same as 1/1000". These parts are, naturally, very small, being less than the diameter of a human hair.

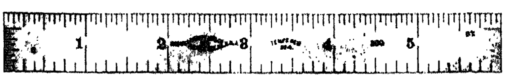
Nearly all of the engine clearances are given in thousandths of an inch. For example, a valve clearance of .010" may be specified. This means that the clearance between the valve stem and the valve tappet or roller is to be ten, one thousandths, or as it is read, ten thousandths of an inch. It will be noticed that this decimal could be read one hundredth of an inch; however, to avoid any possible confusion it is always expressed in thousandths.

For extremely fine measurements, .001" is divided into 10 parts,

giving each part a length of 1/10,000, or one ten thousandth of an inch. This fraction, which is written .0001", is so small that it takes fifteen or twenty of them to equal the diameter of a hair. It is sometimes difficult for the beginner to realize that it is actually necessary for the mechanic to take measurements this small, but when he himself is faced with the prospect of having to make measurements which are accurate to .0001", he will see the importance of the job and will appreciate the delicate accuracy of the instruments which make such measurements possible.

It is possible to take measurements of much less than .0001", but this is done by extremely sensitive laboratory instruments and therefore forms no part of the engine mechanic's job.

Another system of linear measure that the mechanic should know is the metric system. In this system the standard length, one meter, is equal to 39.37 inches. The meter is divided into 100 parts, called centimeters. The centimeter is divided into ten parts, which are called millimeters. Complete tables of the English and metric measures will be found in the back of this book. The metric system is not used extensively in this country, but there are times when a knowledge of this system is required, especially when working on foreign engines.



These rules are about 1-20th of an inch thick excepting the 48" which is about 1-10th of an inch thick.

Fig. I

The illustrations of measuring tools shown here are by the courtesy of the Brown and Sharpe Mfg. Co., who are known throughout the world for their precision machinist's tools.

Steel Scales - Of all the measuring devices used by the mechanic, the steel scale can be considered the most fundamental. There are various types of steel scales, ranging from the thin, flexible variety to those having heavier rigid steel blades. Probably the most popular type of steel scale is that shown in Fig. I, which is 6" long with graduations on both sides. The side shown in the figure is divided into 8ths and 16ths of an inch. The opposite side is divided into 32nds and 64ths. For special purposes, scales are made with divisions of 10ths, 20ths, 50ths and 100ths of an inch, or 12ths, 24ths, and 48ths. Many scales are also provided with English graduations on one side and metric graduations on the other. The scale shown in Fig. I also has what is called end graduations. These are found on either end of the rule, running across the width of the blade. This feature is advantageous when measuring the depth and width of grooves, countersinks and recesses, etc.

A Tempered Steel Rule used with Key Seat Clamps assures a correct layout.

Fig. II

In addition to using the steel scale as a measuring device, it may also be used as a straight edge, such as is required when lay-

ing out fittings, testing the trueness of edges, etc. Fig. II shows a steel scale equipped with two key seat clamps, which adapts the rule to make parallel lines on round stock.

A narrow hook rule, such as shown in Fig. III, is a very convenient tool for the engine mechanic, especially when measuring the depth of a recess, the length of a bolt hole, the depth of a stud, etc. Another convenient form of the steel scale is used with a holder, such as shown in Fig. IV. In this, any of a number of blades may be placed in the holder at various angles so that measurements may be more conveniently taken where space is limited.

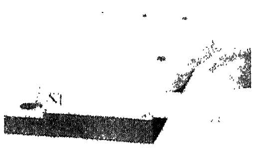


Fig. III

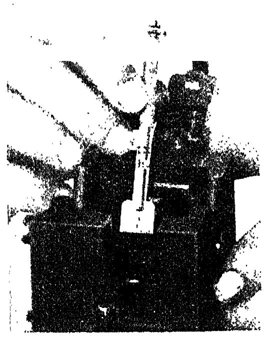


Fig. IV

The pocket slide caliper rule, shown in Fig. V, will be found convenient for measuring the diameter of round stock, the diameter of holes, or similar outside and inside measurements. It is provided with a knurled clamp nut which holds the blade in any desired position.

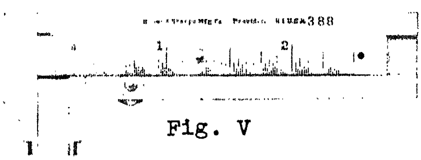


Fig. V

Fig. VI shows a magnified view of the Vernier attachment which can be used on caliper rules. This feature makes possible the calibration of the rule into thousandths of an inch. The following instructions on how to read the Vernier caliper are supplied by the courtesy of the Brown & Sharpe Mfg. Co.

"Reading the Vernier - Fig. VII-A and B shows the Vernier used with a scale which is graduated into 40ths or .025ths of an inch. The Vernier has 25 divisions which are numbered every 5th division and which equal, in extreme length, 24 divisions on the scale, or 24 x 1/40" = 24 x .025" = .600". Thus, one division on the Vernier equals 1/25 of .600" = .024". Therefore, the difference between a division on the

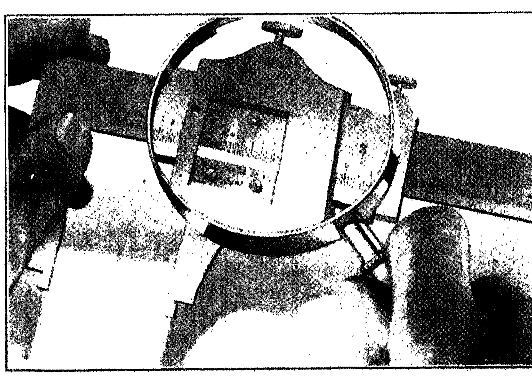
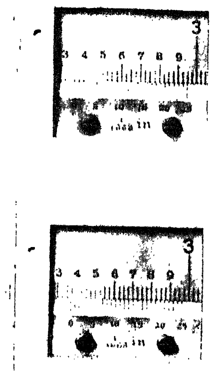


Fig. VI

Vernier and a division on the scale = .025" - .024" = .001".

"When the reading is exact, with respect to the number of fortieths of an inch, the zero on the Vernier coincides with a graduation on the scale - either inch, tenth or fortieth, as the case may be. This leaves a space between lines on the scale and the 1, 2, 3, 4, 5, 6, etc. lines on the Vernier or .001", .002", .003", .004", .005", .006", etc. respectively, the difference increasing .001" at each Vernier division in numerical order until, at the 25th graduation, the lines again coincide (see VII-A).

"Thus, when the 1st, 2nd or 3rd, etc. line on the Vernier coincides with a line on the scale, the zero on the Vernier has moved 1, 2 or 3, etc. thousandths of an inch past the previous fortieth graduation to bring these lines together.



A

B

Fig. VII

"To read - Note the inches, tenths and fortieths of an inch that the zero on the Vernier has moved from the zero on the scale and to this reading add the number of thousandths indicated by the line on the Vernier that coincides with a line on the scale.

"Example:- Fig. VII-A shows the zero graduation on the Vernier coinciding with a fortieth graduation on the scale (the second fortieth beyond an even tenth graduation). This indicates that the reading is exact with respect to the fortieths of an inch. The reading therefore equals 2.000" + .300" + .050" = 2.350". Fig. VII-B, however, shows the 18th Vernier graduation coinciding with a line on the scale. This indicates that .018" should be added to the scale reading. The reading, then, equals 2.000" + .300" + .050" + .018" = 2.368"."

Before a mechanic uses a steel scale with which he is not familiar, it is essential that he ascertain the type of graduation on the scale. Many expensive mistakes have occurred by using a scale divided into 10ths instead of 16ths. There is also a shrink rule which apparently is graduated as any other rule, but the division representing an inch is longer than the inch on standard rules. This rule is used in pattern work, so that the patterns will be made slightly oversize to allow for shrinkage of the molten metal. The result of using this rule by mistake, instead of one of the conventional type may lead to a great deal of unnecessary expense.

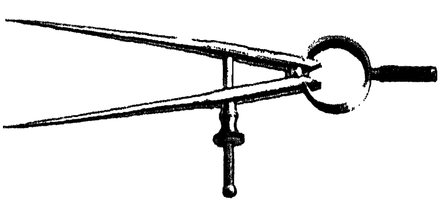


Fig. VIII

Dividers - A pair of tool-

maker's dividers is illustrated in Fig. VIII. One of the uses of this tool is to measure distances over a surface and to transfer these dimensions from one object to another. For example, when laying out a fitting or locating the position for holes, dividers may be adjusted to the correct dimension on the steel scale and measurement then transferred to the work. This is often a more accurate method than attempting to measure the distance with a scale only. Dividers are also used to scribe arcs and circles on metal; however, in this connection it should be remembered that these are precision tools and should not be abused by using too much pressure. Much greater accuracy will result by using one firm stroke rather than several heavy ones. Excess pressure will have a tendency not only to dull the tempered points, but also to spring the legs, which would of course result in inaccurate layout. When scribing arcs and circles on metal it is desirable, if possible, to make a light prick punch mark as a center for one leg. This removes the necessity of applying much pressure to keep the center-leg from shifting.

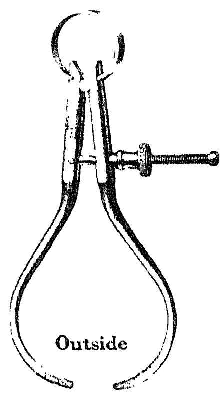


Fig. IX

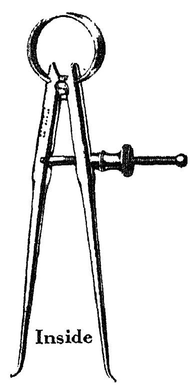


Fig. X

Calipers - The outside caliper (Fig. IX), as the name implies, is a tool for taking outside measurements. It may be used on flat stock, round stock, or irregularly shaped objects. The legs are made of a good grade of spring tempered steel and are so shaped as to facilitate obtaining a true measurement. When using this tool the adjusting screw should not be tightened more than enough to make the points come in contact with the material. Any excess pressure will spring the legs apart, resulting in an incorrect measurement. After the adjustment has been made the distance between the points may be measured with a steel scale. If an extremely accurate measurement is required, the space between the points on the outside caliper should be measured with the inside caliper, shown in Fig. X. When doing this, the outside caliper should be held in one hand and the inside caliper held and adjusted in the other hand, so that the points come in contact with each other. After this adjustment has been made, the distance between the points of the inside caliper may be accurately measured with a micrometer caliper.

A micrometer caliper, with the parts labelled, is shown in Fig. XI. This is a tool which is used for precision measurements, being graduated in .001" or .0001". By turning the thimble the spindle moves in and out, which in turn increases or decreases the space between the measuring faces. The customary pitch of the thread is 1/40th of an inch, or 40 threads to the inch. This means that by turning the spindle one complete revolution the spindle moves 1/40th of an inch, or .025". The lower end of the thimble is marked with

graduations which, when compared to the reference line on the barrel, indicate the number of revolutions made by the thimble, thus when these graduations are counted, the opening between the measuring faces is determined. The following instructions on how to read micrometers were written by the Brown & Sharpe Mfg. Co.

"To read - First note the last figure visible on the scale on the barrel, representing the tenths of an inch. Multiply the number of divisions visible beyond this figure by 25 and add the number of the division on the scale on the thimble that coincides with the line of graduations on the barrel. Then this sum expressed in thousandths, added to the tenths shown, is the reading.

"Example:- In Fig. XII, .200" (2-10") is shown by the figures on the scale on the barrel and one graduation beyond a tenth graduation is also visible while on the bevel on the thimble the graduations show 16 divisions from the zero to the line coincident with the horizontal line on barrel. Then the reading = .200" + .025" + .016" = .241".

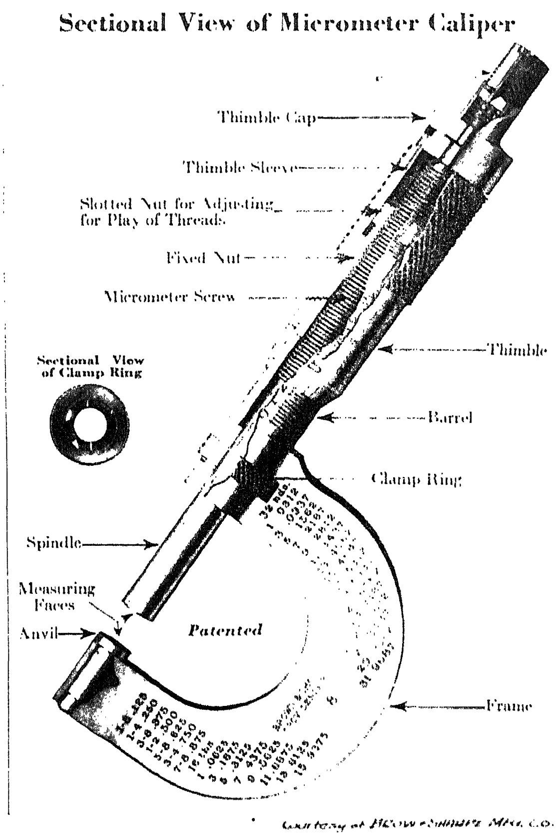


Fig. XI

"To obtain readings in ten-thousandths of an inch a Vernier is employed on the barrel of the Micrometer Caliper. The Vernier used consists of ten divisions, which equal, in over-all space, nine divisions on the thimble. Thus, one division on the Vernier = 1/10 x 9/1000" = 9/10,000". Since each graduation on the thimble = 1/1000" or 10/10,000", the difrerence in space between a division on the thimble and a division on the barrel = 10/10,000" - 9/10,000" = 1/10,000". Since the two zero lines on the Vernier coincide with lines on the thimble when the reading is exact with respect to the number of thousandths, the difference between the lines on thimble and lines on Vernier at numbers 1, 2, 3, etc., equals .0001", .0002", .0003", etc. Thus, when the 1st, 2nd or 3rd, etc., lines coin-

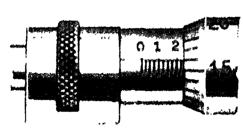
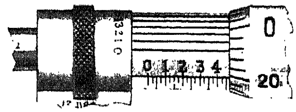


Fig. XII

cide, the thimble has moved past the exact zero setting 1, 2 or 3, etc., 10,000ths of an inch to bring these lines together.



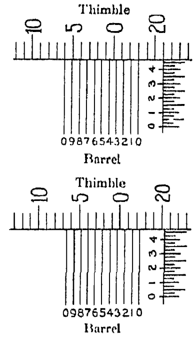
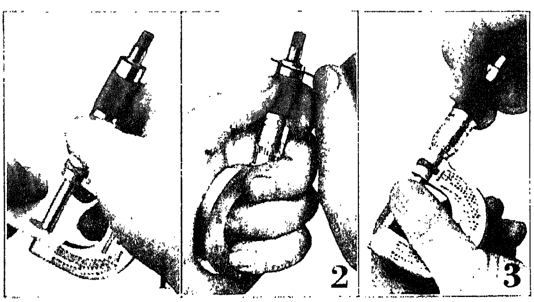


Fig. XIII

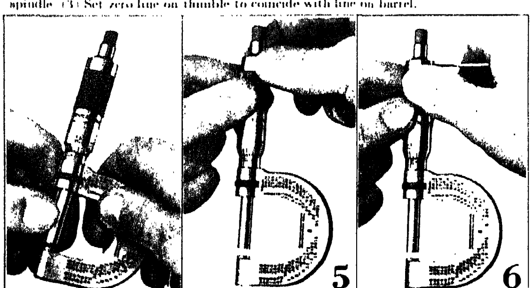
"To read - First obtain the reading for the thousandths in the manner described in the preceding section and then add the ten-thousandths, the number of which is indicated by the line on the Vernier which coincides with a line on the thimble.

"Example:- As shown in Fig. XIII, there are no ten-thousandths to be added, for the two zeros on the Vernier coincide with lines on the thimble; the reading = .4690". In the lower cut the 7th graduation on the Vernier coincides with a line on the thimble, indicating that 7 ten-thousandths should be added to the thousandths reading; the reading = .4690" + .0007" = .4697"."

Some micrometers are provided with a ratchet stop which is used to make the final adjustment between the measuring faces. This stop is so designed that when the measuring faces have the correct pressure on an object, the ratchet automatically slips. This eliminates the possibility of tightening the thimble too tight, thereby obtaining an incorrect reading or damaging the instrument.



(1) Carefully clean measuring surfaces with paper. (2) With anvil and spindle apart, unlock cap then tighten slightly with fingers, to bring tension between thimble and spindle. (3) Set zero line on thimble to coincide with line on barrel.



(4) Turn back *spindle* away from anvil. (5) Tighten cap with fingers for tension. (6) Finally lock with wrench.

Fig. XIV

The set of illustrations shown in Fig. XIV shows how to adjust the thimble in case the micrometer does not read correctly at the zero setting. The first step is to clean carefully the measuring surfaces with paper to remove any oil or other foreign matter. Next, with the anvil and spindle apart and the micrometer held as shown, the thimble cap is unlocked with a special wrench. Tighten this cap slightly with the fingers to bring a tension between the thimble and the spindle. Next, set the zero line on the thimble to coincide with the reference line on

the barrel, as shown in step 3. After this is done, turn the spindle away from the anvil, tighten the thimble cap with the fingers for tension and finally, lock the cap, using the special wrench. This completes the adjustment, but the zero setting should again be checked to make sure the adjustment has not moved during the tightening and locking process.

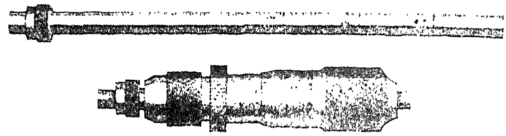


Fig. XV

For taking accurate inside measurements an inside micrometer, such as that shown in Fig. XV, is used. This tool works on the same principle as the micrometer caliper, except that it is inserted inside of the work and has the measuring faces on each end of the instrument. These faces are usually provided with extension bars which increase the capacity of the tool. Fig. XVI shows two common applications of the inside micrometer. Note that these micrometers are fitted with extension handles to hold them in position while the adjustment is being made.

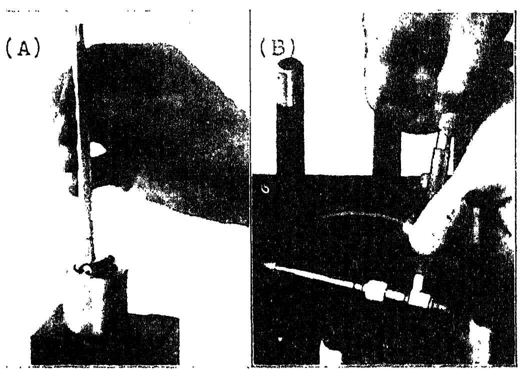


Fig. XVI

Combination Square Sets - A combination square set, such as shown in Fig. XVII, is a useful addition to any mechanic's tool set. Each of the three accessories, the centering gage, the protractor and the square head are clamped to a grooved steel scale. Each may be adjusted to any position on the scale, or may be removed to permit the use of the combination desired. The centering head A, is used to lay out diameter lines on cylindrical objects. This is done by placing the object so that it touches both faces of the centering head. A line scribed along the edge of the steel scale, extending from the middle of the V will be a diameter line. Centers of cylindrical objects may be located by scribing two diameter lines at approximately 90° to each other. The point at which the two lines meet is the exact center.

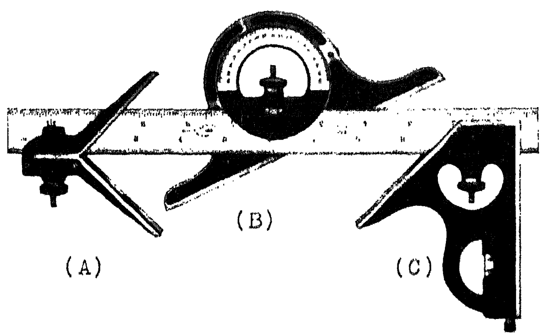
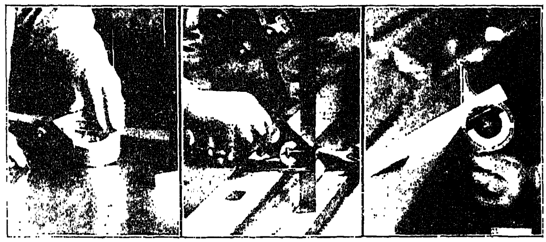


Fig. XVII

The protractor head, B, consists of two parts. The inner part, which is clamped to the scale, contains graduations in degrees from 0 to 180. The outer part, which

rotates on the inner part, has a zero reference mark which is at 90° to its face. By loosening the lock nut, the outer frame can be turned to obtain any desired angle between the face and the scale. Tightening the lock nut secures the head in the desired position. The inside frame is also provided with a spirit level so that it is possible to determine the angle between a horizontal surface and the movable face of the outer frame.



Finding center line of round work is one use for Combination Squares.

A Combinatio Square makes a very c venient depth gage.

Angles are determined quickly and accurately with a Protractor.

Fig. XVIII

The combination square head, C, makes it possible to use the scale as a try square. The square head also has one 45° face, which will be found useful in many jobs. If it is essential that a perpendicular measurement be made, the 90° face of the square can be levelled, using the built-in spirit level. When the head is level the scale is perpendicular. A small, knurled-head scriber is also contained in the square head. Fig. XVIII shows a practical application of each of the above described accessories.

GAGES

It is often more convenient to compare a dimension to a standard than it is to take an actual measurement. This is especially true where the original measurement is difficult or tedious to take, (such as inside measurements of less than one inch), or where many identical dimensions are to be checked. Standard tools which are used for this purpose are called gages, and while there are many types of gages, only those that are used most frequently and those that have a wide range of application will be discussed here.

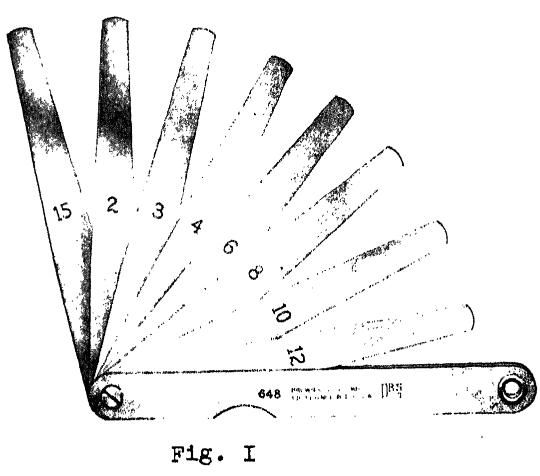
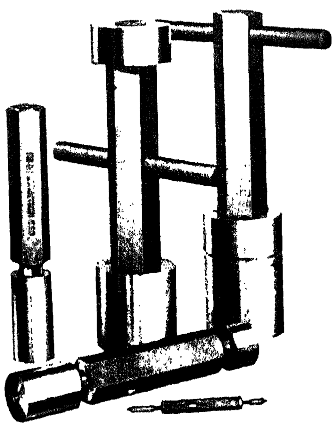


Fig. I

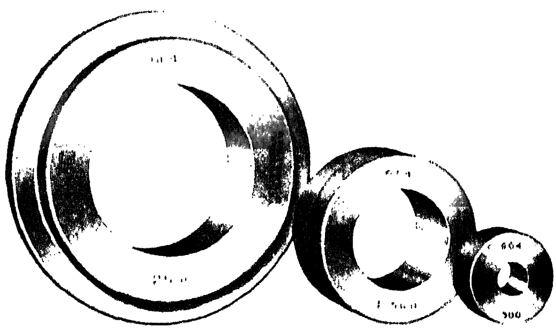
Thickness Gages - The most indispensable gage used by the engine mechanic is a thickness gage, such as illustrated in Fig. I. It will be seen that this tool, which is often called a "feeler" gage, consists of a number of blades that can be folded into a hollow handle. Each of the blades is accurately ground to an exact thickness, which is marked in thousandths of an inch on the blade. To use this tool various blades or combinations of blades are inserted between the two surfaces until a snug fit is obtained.

The thickness of the blade or the total thickness of all the blades used is, of course, the measurement between the surfaces. With the tool shown in Fig. I it would be possible to measure clearances or gaps ranging from .0015" to .0615".

It requires considerable experience to be able to take an exact measurement with a thickness gage, for the accuracy depends to a large extent upon the ability of the mechanic to determine by feel when there is the correct tension on the blade. The beginner should become accustomed to the feel of this gage by measuring objects of known clearance and by comparing his measurements with those taken by an experienced mechanic. When using these gages it is essential that they be kept free from grease, for if there is any foreign matter on the blades it will be impossible to get a correct reading. Care should be taken not to force the blades into openings too small for them as they may be bent or kinked. It will be noticed that the thin blades of the thickness gage in Fig. I are protected, when not in use, by having heavy blades on the outsides. To take full advantage of this feature the gage should be kept closed except when actually being used. If the tool is not to be used for a considerable length of time, the blades should be protected with a coating of light oil. They should be wiped clean with a cloth before using them again.



Plug Gages
Fig. II



Ring Gages
Fig. III

Plug Gages - Several types of plug gages are shown in Fig. II. These are used for measuring the diameter of holes. For checking to see if holes are oversize, a gage with one accurately ground plug is used. The plug is simply inserted in the hole and if any clearance is noted the hole is oversize, for the gage is ground to the largest diameter allowable for the hole in question. For measuring a hole within definite allowable limits, a combination "Go" and "Not Go" gage is used. This is similar to the standard plug gage except that it has two accurately ground plugs, one for the minimum and one for the maximum allowable diameters. In order to be sure the hole is not undersize, the Go gage, or the small diameter plug, must be inserted.

If the Not Go gage, or the larger diameter plug, can be inserted in the hole, it indicates that the hole is oversize. These gages are made of high grade tool steel especially selected for the requirements of the work and are carefully heat treated, hardened, ground and lapped to size. Note: Although the steel used in making gages is carefully alloyed so that it will be as little affected as possible by the temperature, it must be remembered that it does expand and contract with the increase and decrease in temperature. Most gages are designed to be accurate in a standard temperature of 68° F. If they are used when the temperature is greatly above or below this point, due allowance should be made for expansion or contraction.

Utmost care should be taken when using these tools to see that they are not dropped or otherwise abused as a slight scratch or burr may render them unfit for service. When not in use they should be protected from weather by a coating of oil, and stored in a safe place.

Ring Gages - Ring gages of the type shown below are used for measuring the diameter of shafts, pins, rods, or other cylindrical objects. They are made with the same careful precision as the plug gages and are to be used and protected in the same manner. Tolerances are checked with Go and Not Go rings. It is customary for the Not Go ring to have an annular groove cut in the outside circumference to make it more readily distinguishable from the Go gage. The gage shown in the center of Fig. III is a Not Go gage. It is not always possible to check the entire outside diameter of a shaft with a ring gage, as the shaft may have a large diameter on each end and this would make it impossible to gage the diameter of the portion between the ends. If this is the case, the combination ring and snap gage, such as shown in Fig. IV, is used. Using this tool, the entire shaft must pass through the ring, but no part of the shaft must pass through the opening of the Not Go snap gage.

Surface Gages - Surface gages are commonly used in conjunction with a surface plate to transfer accurately distances from the plate to an object. One popular type of surface gage is shown in Fig. V. It will be noted that the tool is being adjusted to a vertical measurement. This adjustment is made by swinging the swivel to any desired position, then sliding the indicator on the spindle to the correct measurement, where it is locked in place. A fine adjustment is then made by turning the small Vernier screw in the base. After the correct setting has been attained it may be transferred to the work. This instrument is definitely a precision tool and should be treated as such.

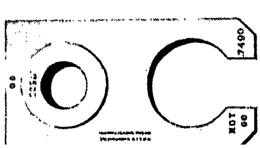


Fig. IV

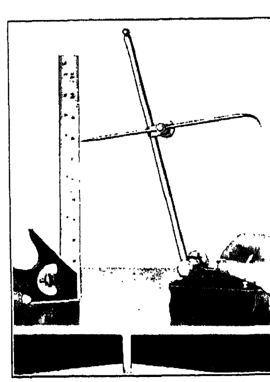
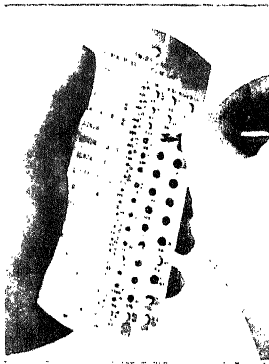
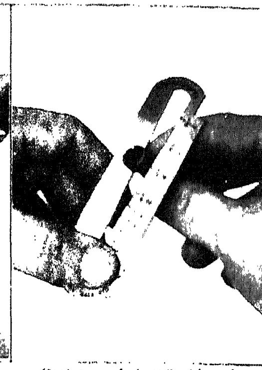


Fig. V





Courtesy of Brown & Sharpe Mfg. Co.

Fig VI Fig. VII

Drill Gages - The size of twist drills is readily checked by the use of a drill gage, such as the one shown in Fig. VI. To use this gage, the drill is merely inserted in the smallest hole possible. The hole is labelled with both the number of the drill and its decimal equivalent. Many drill gages also contain other useful reference material, such as the correct size of drills to use for drilling tap holes, body holes, etc.

Screw Gages - There are many types of gages used to determine the diametric size of wood or machine screws. One of the most popular types is shown in Fig. VII. With this gage, the screw is merely inserted in the large end of the slot and is moved downward as far as possible without forcing. The mark opposite the center of the screw indicates its diameter or number.

Screw Pitch Gage - Fig. VIII shows a screw pitch gage which may be used to determine the number of threads per inch on either a bolt or a nut. Each blade is provided with a saw tooth face, one of which may be fitted to the threads being checked. After the correct blade has been found the number of threads per inch may be determined from the number stamped on the blade. There is very little possibility of making a mistake with this gage except when measuring very fine threads and even then, by exercising a little caution, no difficulty should be encountered.

Dial Gages - Where it is necessary to check the trueness of an object rather than to take its exact measurement, a dial gage, such as illustrated in Fig. IX, is often used. Such an application would be in checking the inside diameter of a constant bore cylinder. The gage is held in an attachment stand, which may be made of various sizes of rods or bars, so that the distance from the base of the attachment to the measuring face of the rod is the standard diameter of the cylinder. The entire

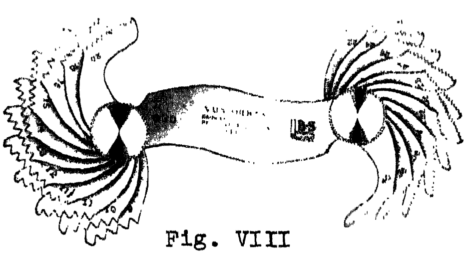


Fig. VIII

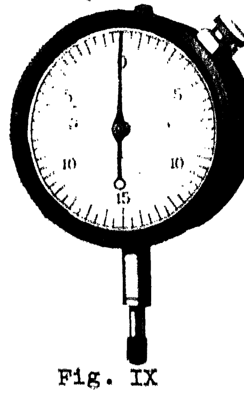


Fig. IX

indicator is now placed in the cylinder and if the cylinder is the correct diameter at that point, the indicator hand on the gage points to zero. The entire cylinder is checked by moving the unit to various points. If the cylinder is oversize in any place the measuring face rod will be allowed to spring out and the indicator will move to the positive, or plus, side until the increased diameter is shown in thousandths of an inch. For example, if a cylinder is .005" oversize the indicator hand will stop at +5. If the cylinder is undersize at any point the measuring rod will be forced in and the indicator will swing correspondingly to the minus side. This gage may also be clamped in a surface gage and used to check the trueness of external measurements or the roundness of material held in lathes, etc.

DRILLS

There is a tendency on the part of a beginning mechanic to overlook the importance of sharpening drills. The twist drill is essentially a cutting tool and should be treated as such. To understand thoroughly how to sharpen a drill, something should be known of the functions of the various parts. The drill may be divided into three parts; the point, the shank and the body. The point of the drill is considered to include the entire cone-shaped tip. The point contains the cutting edges, or cutting lips, Fig. I. The shank is the portion by which the drill is turned. The body contains two spiral grooves on opposite sides running from the shank to the point, called "flutes."

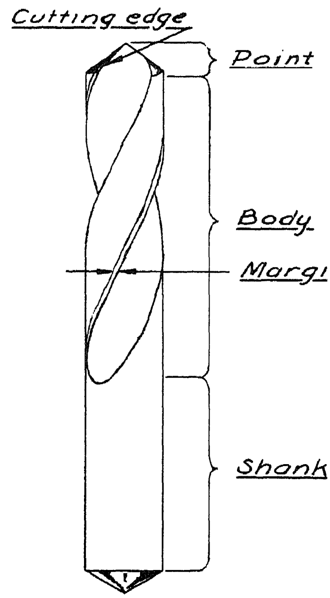
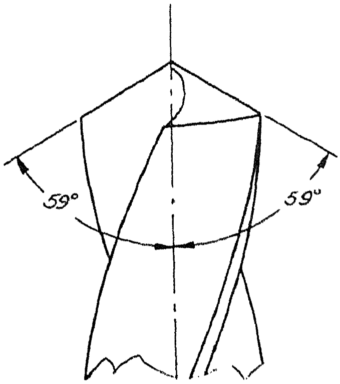


FIG. I.

The flutes of a drill serve not only the purpose of forming the cutting edges of the point but are designed to curl the chips (metal shavings cut by the drill) tightly within themselves, to avoid clogging the hole. Channels are also formed by the flutes whereby the chips may escape from the hole. Another function of the flutes is to allow lubrication to reach the point.

If the entire body of the drill were the exact diameter of the drill itself, much pressure would be needed to overcome the resultant binding of the body on the sides of the hole. This would cause the drill to become heated to the point of drawing the temper from the drill. To avoid overheating, all of the body of the drill is of less diameter, except a small "margin" on the cutting side of each flute. This is called body clearance.

For general purposes the drill is sharpened to the angles shown in Figures II and IV. If the lip angle is more than 59° it is hard to center the drill, as the flatter angle gives the drill a tendency



to walk or slip. An angle of less than 59° on the lips causes the drill to cut less rapidly as the cutting edges are longer. The cutting lips should always have a clearance of from 12° to 15° to allow the lips to penetrate into the metal. This is an important point, for unless the drill is ground with correct clearance here, the surface back of the cutting edge will rub on the bottom of the hole and will not permit the lips to cut. This should be watched closely in grinding drills as it is easy to overlook, especially on drills of small diameter.

Drills should be ground on a fine emery wheel that is surfaced truly. Care should be taken to prevent the drill from getting hot, by dipping it in water frequently while grinding. Grinding drills is not a difficult process, but it requires considerable practice. One of the best ways to learn to sharpen drills correctly is to select a medium size drill, about 3/8" in diameter, and practice sharpening this drill several times. If a drill of much smaller diameter than this is used in practicing, it will be difficult to check the angles. A metal template with the correct angles will be found to be of great assistance in checking the accuracy of your work.

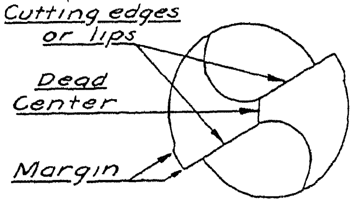


FIG. III

The drill should be held in the right hand and supported near the point with the first finger of this hand. Holding the shank of the drill with the left hand, let the point come into contact with the face of the stone in such a manner that the cutting edge is at right angles with the emery wheel. This will give the lips their angle. By moving the left hand down, the drill pivots over the first finger of the right hand and as the drill point moves upward, the lip clearance is cut.

The cutting angle of 59° has been found to be the best angle for use in drilling such materials as chrome molybdenum, cold rolled steel, tin, cast iron, wrought iron, fiber, etc. For drilling soft materials such as brass aluminum, dural, etc., the drill should be sharpened to a lip angle of approximately 50° as this permits the drill to cut faster. For drilling wood

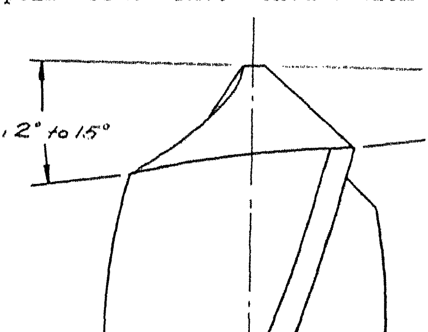


FIG. IV

an even smaller angle is used. In drilling thin sheet stainless steel, a drill with an angle of about 65° is recommended. If this angle is used, greater care must be taken to provide a good center punch or guide hole for the drill, as it is harder to center the blunt point.

REAMERS

Reamers are used to enlarge and true a hole, such as is necessary when installing new bushings, drilling new bolt holes, etc.

FIG. I

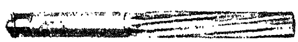


FIG. II

The reamer consists of three parts; the body, the shank and the blades. The shank has a square tang to allow the reamer to be held in a tap wrench, or other similar handles, for turning. The main purpose of the body, of course, is to support the blades.

The blades on a reamer are made of steel, hardened to such an extent that they are very brittle. For this reason great care must be taken in using and storing the reamer in order to protect the blades from chipping. When a hole is being reamed, the reamer should be turned in the cutting direction only, to prevent chipping or dulling of the blades. Great care should be used to assure even, steady turning, otherwise the reamer will "chatter", causing the hole to become marked or scored. To prevent damage to the reamer while not in use, it should be wrapped in an oily cloth and kept in a box.

Reamers of the types shown in Figures I and II can be purchased in any standard size, but are also available in size variations of .001" for special work. Where a number of holes of the same size are to be reamed a solid straight flute reamer is used, as it lasts longer and is less expensive than the expansion reamer.

The solid spiral flute reamer, Fig. II, is used also where many similar holes are to be reamed and is preferred by many mechanics as it is less likely to chatter. The spiral reamer costs slightly more than the straight flute reamer.

For general purposes, an expansion reamer, Fig. III, is the most practical. This reamer is usually sold in standard sizes from 1/4" to 1" by 32nds and is designed to allow the blades to expand 1/32". For example, the 1/4" expansion reamer will ream a 1/4" to a 9/32" hole, and a 9/32" reamer will carry the hole from 9/32" to 5/16". This range of adjustment allows a few reamers to cover the entire field and by using them carefully they will meet almost any need.

Reamers are supplied in two materials; carbon steel, and high speed steel. Generally speaking, the cutting blades of a high speed reamer lose their keenness quicker than a good carbon steel reamer, but after that keenness is gone it will last longer than the carbon reamer before it is beyond average use.

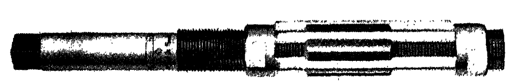
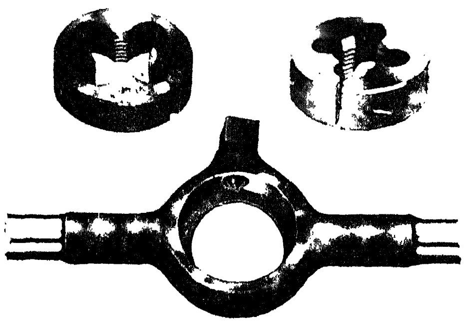


FIG. III

TAPS AND DIES

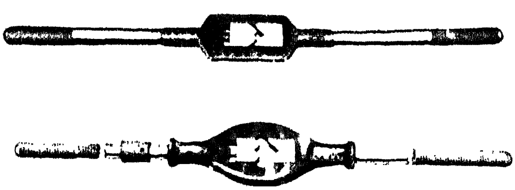
The mechanic often has occasion to cut threads on bolts or studs and on the inside of holes. The first operation is outside threading and the second is inside threading or "tapping." There is no word for outside threading which corresponds to the word tapping, so, for purposes of distinction in the following instructions, the process of cutting an external thread on a bar or rod will be called "threading", as against cutting a thread on the inside of a hole, or tapping.

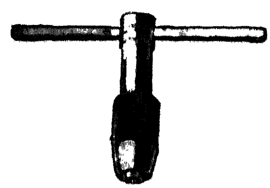


DIES AND STOCK

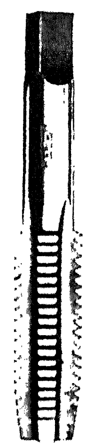
Threading is done with a tool called a "die", usually held in a handle called a "stock." The length of the stock varies with the size of the die, which, in turn, varies with the size of the rod to be threaded.

Tapping derives its name from the tool with which it is done, called a "tap." The tap is held and turned by means of a tap wrench, or in the case of small taps, a tap wrench and chuck. There are many varying forms of taps and dies, but the variations, as a rule, are slight, and those illustrated are typical of the styles usually encountered.





TAP WRENCHES



TAP

Tapping and threading are usually done on machines in production work, but the field mechanic will have to do it by hand.

There are two kinds of threads in general use on bolts, machine screws, studs, etc., or rather it might be better to say, two sets of pitches, as the threads themselves do not differ in form. These are the National Coarse and the National Fine. The National Coarse is the coarser of the two and its use in aircraft is confined almost entirely to machine screws and studs which are screwed into some softer metal like aluminum. The table below compares the number of threads per inch in the two standards in the sizes likely to be encountered in aircraft use. Illustrations by courtesy of Greenfield Tap and Die Co.

Dia. In. -	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
N.C.	28	20	18	16	14	13	12	11	10	9	8
N.F.	32	28	24	24	20	20	18	18	16	14	14

In using a die, be sure that the proper size is selected and that the die is right side up in the stock. The bottom of the die may be distinguished, as a rule, by a slightly larger opening and less sharply defined threads. The top of the die should fit against the top shoulder in the socket of the stock. Tighten the die securely in the stock, clamp the rod to be threaded in a smooth jawed vise, or between blocks of hardwood, and if there is a burr on the end, smooth it off with a file. Put some light engine oil on the rod and set the die on the end carefully, taking great care that it is square with the rod in both directions.

In starting the die, it is usually desirable to hold the handle of the stock near the center, or even to grasp the center and the die with one hand. Once it has been started and two or three revolutions made, the rest is easy. It is desirable to reverse the direction of rotation for a quarter to a half revolution for every complete turn - that is, back the die up a little for every full revolution ahead. This knocks off the chips and will produce a much better thread if the die is not sharp. Do not press down on the die, it will cut just as fast and produce a cleaner thread if left to make its own way. Keep the piece being threaded well covered with oil. In removing the die, lift it off the piece as soon as it is disengaged from the threads for if it is allowed to spin around several times in the reverse direction after it is free it will damage the thread at the end of the bar and make it hard to start a nut on the thread.

If it is necessary to cut threads close to a shoulder, such as the head of a bolt, the procedure outlined above should be followed until the thread can be cut no further, then the die should be removed and screwed on upside down. In this way the full threads can be carried clear to the shoulder, where otherwise the last two or three threads are not fully cut.

Most dies can be adjusted to a slight extent. If it is desired to make an unusually tight fit in the nut or hole, the adjusting screw in the die may be loosened, thus preventing the die from cutting so deep. On the other hand, a loose fit between the parts being threaded may be obtained by tightening the adjusting screw.

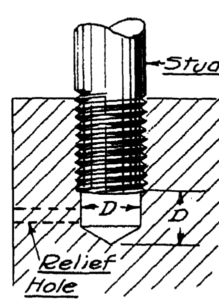


FIG. I

Tapping - The operation of tapping differs from that of threading chiefly in the fact that the threads are cut on the inside instead of the outside. The hole should be drilled in accordance with the table following. If the hole does not go through the material, as in the case of a stud, the drill should be carried at least one diameter past the point where the stud is intended to end, as shown in Fig. I. The purpose of making the hole deeper than is apparently needed is twofold. In the first place, the end of the

tap does not cut a full thread unless it is specifically designed with that in view, in which case it is used only after the thread has been cut as far as possible with another tap. In the second place, chips falling to the bottom of the hole require a certain amount of space. Of course, if the piece being threaded is small enough to handle conveniently, it may be turned upside down and the chips blown out with compressed air. To aid further in cleaning out the threads, a relief hole is sometimes drilled at right angles to the hole to be tapped, smaller than the latter and meeting it at the bottom. This is indicated by the dotted lines in Fig. I.

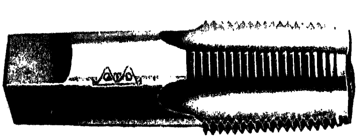
Tap Size	Tap Drill	Drill Dia.
* 2-56	50	.0700
* 3-48	47	.0785
* 4-36	44	.0860
* 6-32	36	.1065
* 8-32	29	.1360
*10-30	22	.1570
*10-32	21	.1590
*12-24	16	.1770
1/4-20	7	.2010
1/4-28	3	.2130
5/16-18	F	.2570
5/16-24	I	.2720
3/8-16	5/16	.3125
3/8-24	Q	.3320
7/16-14	U	.3680
7/16-20	25/64	.3906
1/2-13	27/64	.4219
1/2-20	29/64	.4531
9/16-12	31/64	.4844
9/16-18	33/64	.5156
5/8-11	17/32	.5312
5/8-18	37/64	.5781
3/4-10	21/32	.6562
3/4-16	11/16	.6875
7/8-9	49/64	.7656
7/8-14	13/16	.8125
1-8	7/8	.8750
1-14	15/16	.9375

* Machine Screws

In the actual operation of tapping, the same procedure is followed as in threading, as regards starting the tap, using plenty of oil and backing up a half turn after every full revolution ahead.

In aircraft, the fittings for gas and oil lines, drain plugs and other parts of the "plumbing" which are threaded use the "pipe" thread. Both inside and outside threads are tapered so that when the parts are screwed together they fit as tightly as desired, thus producing a leak-proof joint. The nominal size of these threads is the diameter of the inside of commercial water pipe. A 1/4" pipe would be used in house plumbing to make threads for a water or illuminating gas pipe with an inside diameter of 1/4". In aircraft, the tubing used for fuel and oil lines is designated by the outside diameter of the tubing, which has a much thinner wall than ordinary water pipe. This gives rise to some confusion as a fitting with a 1/8" pipe thread would be used on copper tubing 1/8", 3/16", 1/4" or 5/16" outside diameter. The following table will clear this up.

Tubing Size-	1/8	3/16	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1
Pipe Size-	1/8	1/8	1/8	1/8	1/4	3/8	1/2	3/4	3/4	1

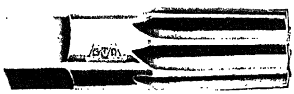


PIPE TAP

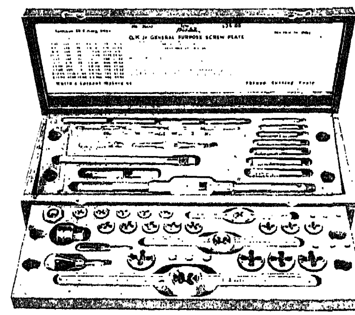
The taper on most pipe threads is the American National Standard Taper, which is 3/4" in one foot. When tapping pipe threads, the hole, of course, should be tapered. The taper is made with a taper pipe reamer and care should be taken not to ream too deep,

as a loose thread will result. The same thing applies to tapping. The tap should be run in until the threads are just covered, and no further. The procedure in tapping pipe threads is the same as with any other kind of thread. The hole before reaming should be the diameter of the small end of the reamer. The table below gives the proper drills to use.

Pipe Reamer-	1/8	1/4	3/8	1/2	3/4	1
Reamer Drill-	"O"	13/32	35/64	43/64	7/8	1-7/64
Drill Dia.-	.3160	.4062	.5469	.6719	.876	1.1094



PIPE TAP REAMER



Courtesy GREENFIELD TAP & DIE CO.

SCREW PLATE

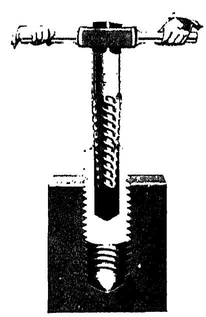
If reamers are not available, the following table gives the sizes of drills to be used without reaming afterwards. A less satisfactory job will result, however.

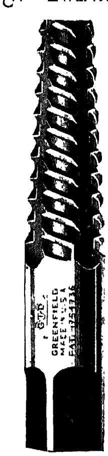
Pipe Thread-	1/8	1/4	3/8	1/2	3/4	1"
Tap Drill-	R	7/16	37/64	23/32	59/64	1-5/32
Drill Dia.-	.339	.437	.578	.719	.921	1.156

Taps and dies are usually purchased in complete sets called screw plates. One of these is illustrated. The set shown is very complete and an outfit such as this is an important part of every mechanic's tool chest.

SCREW EXTRACTORS

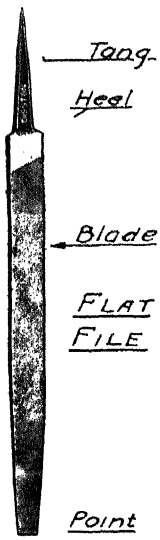
The mechanic sometimes has occasion to remove a stud or cap screw that has been broken so that it cannot be removed in the conventional manner. A screw extractor such as illustrated should be used for this job. The correct procedure is to center punch the exact center of the exposed end of the broken stud. It should then be drilled, using a drill approximately 3/4 of the stud diameter. There should be a substantial depth to the hole. The screw extractor, held in a tap handle or similar device, is inserted into the hole and turned in the counter-clockwise direction. It works its way in until its taper causes it to grip the sides of the hole. Further turning unscrews the stud without damaging the threads in the hole.





FILES

The file is one of the most universally used tools. While it is made primarily for use on metal, it can be used with equal success on many of the composition materials, such as hard rubber, fiber, etc. Files are used for every type of cut from the very rough cut, where removing excess material quickly is the main objective, to a cut so fine as to be almost polishing. To fit such a large variety of needs the file itself is made in many shapes and cuts. To attempt to explain the uses and characteristics of all the types of files would be almost impossible, but a general conception of the varied use of the file can be learned from the fact that one large file manufacturer makes more than 250 styles and more than 1,000 different cuts and sizes of files.



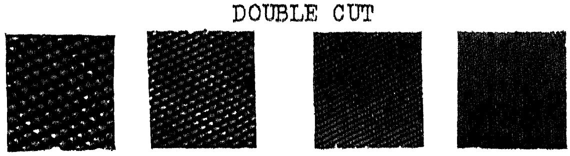
The most common shapes of files are the flat, half round, mill, round, square and the triangular shaped file, called the three-square, or three-cornered file. Probably the most widely used shape is the flat file.

"Cut" refers to the kind of teeth on a file. The single cut file has but one course of chisel shaped grooves, running diagonally across the blade, forming the teeth. The double cut file, in addition to the single cut teeth, has a second finer course of chisel grooves crossing the first, forming diamond shaped teeth. The rasp cut file, used on wood or other soft material, has individually cut teeth which are made by raising the metal with a punch. Each of the three types of cuts are supplied as standard in four grades, the rough cut, bastard cut, second cut and smooth cut, as shown below.

SINGLE CUT

Rough Bastard Second Smooth

DOUBLE CUT



Rough Bastard Second Smooth

Hints in Using a File:

1. Never use a file without a handle, as the tang is likely to cut the palm of your hand or wrist if the file slips. A handle also permits a better grip, insuring a more even pressure. Make sure the handle is tight on the tang.

2. File with a slow, even stroke, using the entire length of the blade.

3. As the file teeth point forward, the file cuts only on the forward stroke. On the return stroke the file should be raised slightly to prevent dulling the teeth.

Note: In filing soft material such as aluminum, dural, lead, etc., the file should be drawn back over the metal as the teeth are cleaned on this stroke.

4. The blade of a file has been hardened to such an extent that it can be broken easily by tapping it on a vise or bench. For this reason, never attempt to clean the file by tapping it against anything.

5. The material to be filed should be held firmly to prevent the file from chattering on the work.

6. Use enough pressure on each stroke to keep the file engaged in the cut, thereby avoiding glazing the file by slipping.

7. When filing sheet metal held in a vise, do not allow it to extend far beyond the jaws of the vise, as this will allow the material to vibrate.

8. Use a file brush and card to clean the choked gullets between the teeth.

9. In using a round file, a smoother cut will result if the file is rotated slightly on the forward stroke.

10. To avoid cutting hollows in the material when using the round or half round file, a slicing motion should be used on the forward stroke.

11. Small rod or bar stock may be cut by nicking the material on opposite sides with the corner of a file and then bending the material.

12. The file is a cutting tool. It should not be thrown with other tools or allowed to become rusty. The file should never be hammered or used as a pry, as the blade is very brittle and will break easily.

SOLDERING

Soldering is a means of obtaining a positive bond between metals, usually wires or sheets. In airplane mechanics it is used to make low resistance electrical connections, leak-proof tank seams, etc.

Solder is an alloy of lead and tin, but has a melting point lower than either of its components. It is fused or melted upon the parts to be joined by either a torch or a soldering iron.

The torch is employed on large work, where the extent of the seam or joint is great, and where beauty of finish is not important. It may be either gas or acetylene fired. As the gasoline blow torch is by far the more common type in use, description will be limited to that type.

The Blow Torch - Fig. I shows a common type of gasoline blow torch. The tank is filled about two-thirds full of clean, unleaded gasoline. The pump is operated until sufficient pressure is built up in the tank to cause the gasoline to flow when the valve is opened. The torch being cold, the gasoline comes out in liquid form, and drips into the priming pan. When the pan is partially full, the valve is closed, and the gasoline lighted and the flame heats the perforated nozzle. When the nozzle is hot, the valve is opened slightly, allowing the gasoline vapor which has been formed, to flow from the nozzle, where it burns with an almost colorless flame.

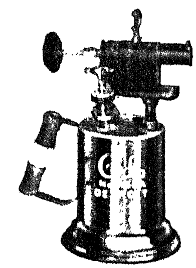


FIG. I

Soldering Irons - The soldering iron is used for smaller work. The name is misleading, since all soldering "irons" are made of copper. It may be heated by a blow torch, gas flame, charcoal or electricity. Electrically heated irons are special types. Figs. II and III show both the plain type and the electrical type. The point, or working face of the iron, should be relatively blunt, as in Fig. IV, not sharp, as in Fig. V. The purpose of the iron is to retain and transmit heat, and if it is too thin and sharp it will cool too rapidly. Generally speaking, a large soldering iron should be used wherever possible, as it will hold heat longer than a small iron. The iron should be cleaned, or tinned, by rubbing it against a block of sal-ammoniac, or in a puddle of rosin and solder.

Common Iron

FIG. II

Electric Iron

FIG. III

Flux - Solder will only stick to clean metal. Therefore, it is necessary to scrape or sandpaper the parts to be joined until they are bright. Even then, there is still likely to be a small quantity of dirt on the metal, and the application of heat will produce oxides which will prevent the solder from adhering. To eliminate this difficulty a "flux" is used, which dissolves the oxides, leaving the metal clean.

Acid Flux - Probably the most powerful flux that is used for soldering is muriatic acid which has been "cut" with pure zinc. Muriatic acid can be purchased from almost any

drug store. It should be kept in a tightly closed bottle, and plainly marked "ACID - POISON." To cut the acid for use, a small quantity can be placed in an open neck bottle or glass. Pure zinc such as can be found in the exterior cover of an old dry cell, should be cut into small pieces and added to the acid. Bubbles will be formed immediately and the acid will not be ready for use until the bubbles cease. An excess of zinc should always be kept in the solution. CAUTION: Acid flux should never be used to clean electrical wires, control wires, or any other small work, as the acid has a tendency to keep eating and thereby weakening the part. If an acid flux is used, the parts should be washed carefully to remove as much of the residue as possible. Acid flux should always be applied with a swab and not allowed to come into contact with the hands, eyes, clothing, etc.

Properly Shaped

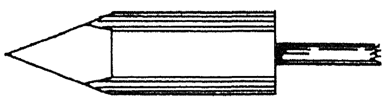


FIG. IV

Poorly Shaped

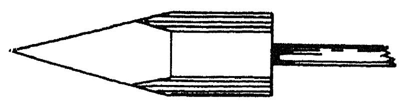


FIG. V

Soldering Paste - Various soldering "pastes" are made to serve as a flux. Soldering pastes are as a rule not as strong a cleaning agent as the acid flux, but being in a paste form it is more convenient and safer to handle. The stronger fluxes are suspended in a wax or grease and it is often believed that the presence of the wax or grease will prevent any corrosive action from the flux. This is not strictly true, and for this reason the ordinary soldering pastes should not be used for delicate electrical connections, etc. Even though soldering pastes are termed "non-corrosive", the completed bond should be thoroughly washed with water.

Rosin - Rosin can be used quite effectively for a soldering flux, with little fear of harmful after effects. It is widely used in the soldering of wires and radio connections. To aid in the use of rosin flux, several manufacturers have made a hollow wire solder that contains a rosin core.

Soldering Hints:

1. The material must be clean and free from any dirt, grease or rust before the proper flux is applied.

2. The soldering iron must be the correct temperature. If it is too cold the solder will lump and not produce a positive bond. If it is too hot the solder will not flow evenly, but will have a tendency to follow the iron.

3. If changeable peacock colors are noted in the soldering iron (copper) the iron is too hot.

4. In soldering connections, the wires must first be mechanically secure.

5. While it is possible to solder overhead, much time will be saved if it is possible to place the work flat.

6. Very often it will be found convenient to mount the iron in a bracket, as this allows both hands free for the soldering.

7. A soldering job such as an eye terminal in flying cable, etc., may be improved in appearance by warming the solder slightly with the torch and wiping the excess solder off with a rag.

8. Material being soldered should be held or preferably clamped, firmly. Any shifting of the parts just as the solder is solidifying will produce internal fractures in the bond. These fractures are more dangerous, as they are not readily discernable.

9. If soldering on a tank that has at one time contained gasoline, keep the torch clear of the tank, and make sure the tank itself has a sufficient vent.

10. Small parts to be coated with solder may be dipped into a ladle of molten solder.

CHAIN HOISTS

A typical chain hoist is illustrated in Fig. I. Equipment of this kind is used frequently when removing or replacing engines, heavy propellers and similar objects, or wherever it is necessary to raise or lower a heavy load. A mechanic should not only be familiar with the correct use of a chain hoist, but should be aware of the dangers involved.

Chain Hoist
Fig. I

In use the hoist is suspended by the hanger hook, a, directly over the object to be lifted. The load is attached to the load hook, b. By pulling on one side of the continuous hand chain, c, the load is raised, and by pulling on the other side of the same chain it is lowered. As the hand chain moves, it turns the large overhaul wheel, d, which actuates a set of reduction gears contained in the main housing e. A specially designed load chain sheave, which is driven by the reduction gears, rotates to raise or lower the load hook. There are, of course, many types of chain hoists, with various gear ratios and load capacities. However, those having a one, three, or five ton capacity and a gear ratio of three to one, or five to one, are used frequently.

Probably the most important single factor contributing to the safe use of a chain hoist is its secure suspension. Not only should the hanger hook be properly attached to its support, but the support itself should be inspected to make sure that it will stand the load and is in no danger of tipping, sliding or slipping. This point can-

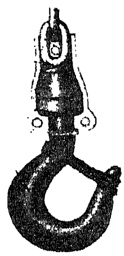


Fig. II

not be over-emphasized, as serious damage and possible injury is likely to result if the support fails.

The hooks are so shaped that there is not much possibility of the load slipping off, even if it is jarred or jerked. However, there is a possibility that it might and to guard against this, the hooks should be "moused", or safetied, as shown in Fig. II.

Soft brass wire, light line, or any similar material may be used for this purpose and there is no definite rule as to how it should be done. The point to be remembered is that the hook opening should be lashed so that it is impossible for the load line to slip off.

ABRASIVES

Abrasives are usually classed as materials and not as tools, but inasmuch as their proper selection and use is of so much importance they will be described briefly here.

Nearly everyone is familiar with the use of sandpaper as an abrasive, as it is used extensively for smoothing all types of woodwork. It is supplied in various grades, ranging from the fine grit #000 to the coarser #3. This material is not satisfactory for working on metal parts, as the silicon base grit is not hard enough to cut metal efficiently. If it must be used in case of emergency, special care should be taken to use as fine a grade as possible, to avoid scratching the metal. It is often advantageous to dull the sandpaper by rubbing the abrasive sides together, which will remove most of the sharp edges and most of the loose grit. Naturally, any material on which an abrasive has been used must be thoroughly cleaned afterwards. A somewhat more satisfactory type of abrasive for use on wood is garnet paper. This is a little more expensive but will give greater service and will not fill up as readily.

Emery cloth is used extensively for cleaning and polishing metal parts. It consists of finely ground particles of emery glued to a tough cloth backing, and ranges from the fine #000 to the coarser #3. When used for cleaning or polishing metal parts great care should be taken that the grade used is not too coarse, as this abrasive often cuts more quickly than is expected and a scratched or uneven surface may result. For finer polishing work, emery cloth should be lubricated with cylinder oil. If it is necessary to obtain a high polish on steel surfaces, crocus cloth is used. This is also an emery base abrasive, but is much finer even than #000 emery cloth.

Another material that is used frequently to obtain a high polish is ground pumice stone. This comes in powdered form and may be used either plain or with the addition of a few drops of water or oil. Pumice makes an excellent polishing compound but is often less convenient to use than crocus cloth. An inexperienced mechanic should never attempt to fit parts with emery cloth, unless he is absolutely certain of the procedure.

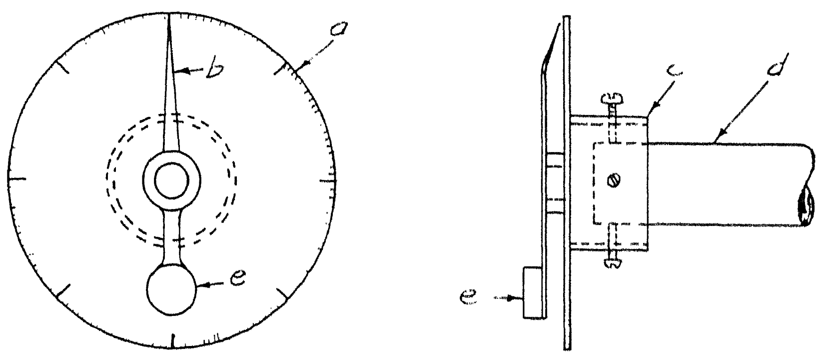
Valve grinding compound is a powdered carborundum abrasive sus-

pended in a composition paste. There are two general types, the oil-mixed and the water-mixed. The former is thinned by the addition of oil and the latter by the addition of water. While these abrasives are used mainly for grinding valves, they are frequently used when grinding piston rings or lapping parts.

Steel wool, which consists of matted steel cuttings, has many uses in aviation for cleaning and finishing parts. Steel wool can be used with equal success on wood, paint, fiber, metal and many other surfaces, providing the correct grade is selected. Grade #0, which is the finest, is about equivalent to crocus cloth or pumice stone and is used to produce a high polish. The medium grade, #1, can be compared to #0 sandpaper. The coarsest grade, #3, is about equal to #1 or #2 sandpaper. Steel wool should never be used on any engine part unless it is possible to clean the part thoroughly before assembly, as the small shreds of steel wool may get into the engine and later cause serious damage.

TIMING DISKS

Many engines are built that do not have a complete set of timing marks indicated on some rotating part. For this reason it is necessary for the mechanic to measure the crankshaft rotation in degrees by other means for the purpose of timing the engine. There are several types of timing disks, but one of the most popular is the universal disk, shown in Fig. I. It consists of a disk, a, graduated



UNIVERSAL TIMING DISC FIG. I

in degrees, a pendulum indicator, b, and a collar, c, for attaching the disk to the engine crankshaft, d.

The disk rotates with the crankshaft and the weight, e, causes the ball bearing mounted indicator to remain vertical. The pendulum indicator cannot be used except when the crankshaft is approximately horizontal. If it is necessary to use the timing disk when the engine crankshaft is vertical, as may be the case when the engine is in a stand, a pointer, or indicator, can be improvised and attached rigidly to the engine.

TOP CENTER INDICATORS

Many times a mechanic has to locate the exact position of the crankshaft when a piston is on top dead center. Probably the simplest way of doing this is to remove a spark plug and insert a smooth stick or a soft wire of large diameter into the cylinder until it touches the top of the piston. By rotating the crankshaft it is possible to feel the movement of the piston. However, this method is not exact, due to the fact that there is only a slight vertical movement of the piston near its top center. This makes it difficult, if not impossible, to tell just exactly when top dead center has been reached. For purposes of timing the engine more accurate results must be obtained. The exact top dead center may be located with a top center indicator and a timing disk.

Top center indicators, similar to that illustrated in Fig. I, may be purchased, although they are usually made by the mechanic. The essential parts are an old spark plug shell, spring wire and a fiber plug. The spring wire, w, is insulated from the shell by plug, p, made of fiber or other non-conductive material. The external end of the wire is provided with a positive terminal, i, and the internal end is made round by adding a ball of solder. The indicator is grounded to the engine through the shell. A single dry cell, b, and a suitable low voltage light, l, connected as shown in Fig. I, are needed to complete the indicator. Its operation is simple. When the wire w is raised, it makes contact with the contact point c, which is grounded through the shell. Thus, the circuit is completed and the light flashes on.

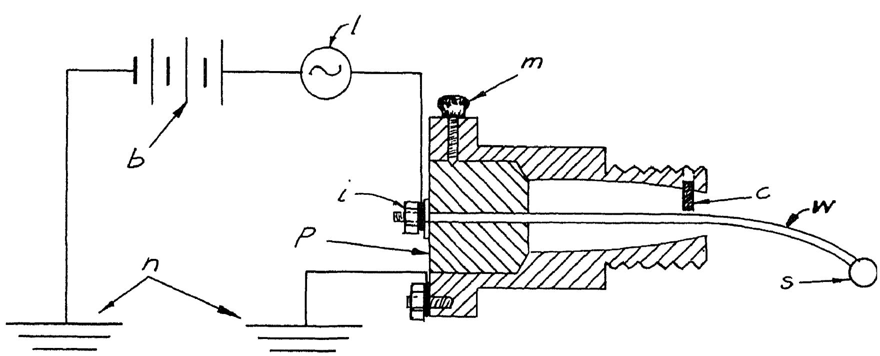


FIG. I

To find top dead center with the aid of this device, a spark plug should be removed from the cylinder which is being used for the purpose, and the indicator inserted in its place. The piston, of course, should be near the bottom of its stroke so that it will not interfere with the adjustment of the indicator. After the shell is secured in place the pin m should be lifted and the fiber plug rotated so that the ball of solder on the end of the wire is at its lowest point. Note: Due to the different arrangement of spark plug

openings in various types of engines, the wire may have to be bent so that the upward travel of the piston will cause it to make contact correctly. It is desirable for the piston to make contact with the wire about 30° before its top center. After the wire has been arranged so that it will operate correctly, the pin m should be lowered to prevent the fiber plug, and consequently the wire, from turning.

The timing disk is now attached to the engine, disregarding the degree position indicated. The crankshaft may now be turned very slowly in one direction until the piston forces the wire upward to make contact. This naturally will be indicated by the light. At this point a reading should be taken of the timing disk setting. As an example, let us assume this reading is 78°. After this figure has been noted, turn the crankshaft in the opposite direction until the light again flashes on. This will mean that the piston is the same distance from top center, but the crankshaft was revolved in the opposite direction in order to place the piston in this position. Consequently there will be a new position indicated on the timing disk. This new reading should be noted along with the previous one. We will assume this new reading is 142°. As both readings were made when the piston was exactly the same number of degrees from top dead center, this point can be located by finding the number of degrees between the two readings, and dividing by two. To complete the example used here, - there will be a total of 64° between the two readings, 142° - 78° = 64°. This angle of 64°, or the difference between the two readings, should be divided by two, giving 32°. Then, by adding 32° to the first reading of 78° the position of top dead center is found to be 110°.

The top center indicator should now be removed and the crankshaft turned until the timing disk reads 110°. The engine is now on top dead center of the timing cylinder and, if desired, the timing disk can be shifted so that it reads zero. While doing this great care should be taken not to rotate the crankshaft.

To ascertain whether or not the piston is on the compression stroke, two methods are commonly employed. The first method is to remove a spark plug on the desired cylinder, hold the thumb over the opening and to turn, or have an assistant turn, the propeller rapidly in the direction of normal rotation. When a positive pressure is felt on the thumb the cylinder is on the compression stroke. However, it is usually more satisfactory to observe the action of the rocker arms on the cylinder. Simply turn the propeller in the correct rotation until the intake valve closes, which means that the piston is moving upward on the compression stroke. When the piston reaches the top of its travel as indicated by the timing disk, the engine is said to be on top dead center of the compression stroke or top dead center of the power stroke.

CHAPTER 5
SERVICING AND OPERATING

Although this book is primarily intended for the mechanic rather than the pilot, it has been considered desirable to include a certain amount of information on the actual operation of the engine. As is the case with all other sets of instructions, these must necessarily vary with each type of engine. Hence, if possible, the handbook of the manufacturer should be consulted before attempting to operate any engine. However, if no handbook is available, it will be found that the information contained in this chapter is sufficient to permit safe handling of any conventional type of aircraft engine.

SERVICING THE ENGINE

This is one of the simplest duties that the engine mechanic has to perform. Yet, as with all other engine work, it must be done carefully and conscientiously. It is here that the mechanic is usually started on his career; therefore it is here that he must prove his efficiency and dependability. He should never complain about not being given a more important job, but should consider this work in its true light, as a necessary and essential part of aviation, a job upon which the success or failure of the flight often depends.

CARE OF THE GASOLINE SYSTEM

There is more to refueling an airplane than simply filling the tanks with gasoline. The job starts with the instructions of the pilot or chief mechanic. It is extremely important in this connection that the mechanic in charge of the actual refueling thoroughly understands, and if necessary makes notes of, the exact amount and kind of gasoline wanted and in which tanks the fuel is to be placed. Many pages could be written about the sometimes disastrous results of not understanding or not carrying out these instructions exactly. The work is so important that several large airlines require the pilot to check this item personally before each flight, just to make sure that it has been done correctly.

The handling of aviation gas should be done very carefully to avoid spilling. Gasoline spilled on the person may cause serious burns. Particular pains should be taken to prevent any gasoline from getting on the face or in the eyes. Ethyl gas, especially, is quite poisonous. Needless to say, smoking should not be permitted anywhere near by when gasoline is being handled.

It is essential that <u>all</u> of the fuel that goes into an airplane be <u>clean</u>. Great care must be taken to avoid use of any dirty equipment. Any funnels that are used must be clean and preferably rinsed with gasoline before use. The hose nozzle should be cleaned and care taken not to let it fall on the ground.

The funnel should be placed in the filler neck of the tank in such a manner that the weight of the funnel and gasoline is not on the filler neck. The tank necks are often bent when this precaution

is not taken, sometimes causing the tank proper to buckle and consequently crack at some point.

When filling a fuel tank from a hose (the customary method on large airports), it is essential that the nozzle of the hose be grounded or connected electrically to the tank. The reason for this requirement is that the friction produced by the gasoline flowing through the hose and into the tank builds up a charge of static electricity. Such a charge having been built up, when the nozzle is removed from the tank an electric spark may occur which will ignite the gasoline. Many serious fires have been caused by the neglect of this simple but important precaution. The funnel or nozzle may be grounded by the use of a short piece of wire provided with clips at each end. One clip is attached to the funnel or nozzle and the other to the tank. In addition, a similar wire should run from the nozzle to the earth or some suitable ground. If the fuel is being drawn from a large underground tank, care should be taken to provide a suitable electrical connection between the nozzle and the tank itself.

There is great danger in refueling during or just before a thunderstorm, particularly if the ship is of all-metal construction, since, under such weather conditions, large metal surfaces may become charged with static electricity from the air. Hence, particular precautions with respect to grounding the entire airplane should be taken if it becomes necessary to refuel. The safest procedure is to avoid refueling, if possible, until the danger no longer exists, or, in other words, until the weather conditions have improved.

Water in Gasoline - Great care must be taken to eliminate any chance of water entering the tank. If the presence of water in the gasoline is at all possible, some precautions to strain the gasoline must be taken. The most common practice in this connection is to strain the gasoline through a chamois skin which has been tied loosely over the mouth of the funnel. Water will not pass through the chamois skin. If this is done as a general practice, the chamois skin must be removed occasionally and washed with soap and water to remove the accumulated sediment which clogs it. After washing, it should be thoroughly air dried and then rinsed in gasoline before it is used again in the funnel.

Straining gasoline through a chamois skin is a slow process and many times "pool table felt" is used in place of the chamois. This proves quite satisfactory and also much faster. However, if this method is used, water should not be allowed to accumulate on the felt as it will eventually pass through.

Several patented funnels are now on the market which are claimed to prevent any water from entering the tank. Many of these are satisfactory but there are some which are not. If a funnel of this type is used it is best to test it previously.

Gasoline that has been stored in five- or ten-gallon cans must be strained to eliminate all water and sediment caused by condensation and rust.

Most refueling trucks or underground storage systems are equipped with some type of water separator which filters the gas before it is delivered to the tank in the airplane. Since these devices vary with different installations, specific instructions with respect to them cannot be given. However, the location of such separators should be determined and the separators themselves periodically checked and drained of any accumulated dirt or water.

General Rules in Fueling - Whenever a ship comes in to the hangar, the fuel in each tank should be measured with a clean measuring stick and the amount noted. Some stations keep a supply of standard forms for this purpose which, when properly filled out, are presented to the pilot. In most cases such service is appreciated and frequently results in the sale of fuel or oil.

After fueling, be sure that the gas tank caps are securely replaced. Such caps should be provided with a chain, so that if they should become loose in the air, they will not blow back with possible damage to the after portions of the airplane. The condition of these chains should be checked, and if the ends are not properly secured, they should be repaired.

Make sure that the gas tank vent is open.

Never step except where a step is provided.

Never drag the hose over the wing, struts, windshields, etc. Treat the airplane with respect.

Do not overflow the gas tank nor allow gasoline to spill from the funnel.

Do not sit on the wing if it can possibly be avoided.

In some cases it is desirable to have a line attached to the hose to support the weight of the hose. This line should be tied not to the filler neck, but to some part sufficiently strong to withstand the strain.

After the refuelling has been completed, remove all rags, funnels, etc. Replace the measuring stick, if it is commonly kept in the ship.

Strainers - All gasoline strainers should be cleaned by removing the screen and draining the water trap. Examine the screen for any accumulation of dirt, rust, etc. and if any undue amount of sediment is found, report this condition to the chief mechanic or pilot. Replace the strainer screen and close water trap. Safety the strainer and test it for leaks by turning on the gasoline and building up pressure with the hand wobble pump, if such is supplied. Caution: This pressure should not exceed 6 lbs./sq.in., as more may damage the carburetor.

After the ship has been fueled, it is an excellent plan to drain the sumps of the fuel tanks, if they are provided with drain cocks. If only a pipe plug is installed, draining the sump when the

tank is full of gas is a rather difficult procedure. In this latter case, the sumps should be drained before filling the tanks.

It should be needless to say that refueling should never be done in the rain unless proper precautions are taken to prevent rain water from entering the tank.

SERVICING THE OIL SYSTEM

The importance of the careful servicing of the oil system cannot be overemphasized. Any aircraft engine must have a sufficiency of clean oil of the correct grade or it will not function properly for long.

Adding Oil - In adding oil to the lubrication system the following outline should be carefully observed.

1. Remove the cap or cover to the oil storage reservoir (oil tank or engine sump) and measure the oil in the system if possible.

Note: Oil expands approximately 10% when heated, therefore if the oil is measured while hot the level will be proportionately higher.

Note: The capacity of the system should be marked on the tank or on the engine near the oil cap.

2. After ascertaining the amount of oil needed, report this to the pilot or mechanic in charge and find out what type of oil is being used. This is important for two reasons. First, it gives the person in charge of the ship the information necessary to estimate the amount of oil being used by the engine and second, insures the addition of the same type of oil.

3. If any funnels or other equipment are to be used, make sure that they are clean and free from water.

Note: If there has been any possibility of water getting into the oil, pour the oil into the system through a funnel very slowly. Watch the oil for any globules of water and if one is seen remove the funnel before it has a chance to get into the system. Even a few drops of water in the oil have caused serious damage to the bearings.

4. After the oil has been added, measure with a graduated gage if possible to make sure the level is correct. If the oil does not come to the correct level, or if it exceeds the level, do not assume the condition is satisfactory, but ask the person in charge.

Note: Too much oil in the system may cause serious damage, such as fouling the spark plugs or possibly expanding to the point where the tank or some of the lines will burst. The first indication of too much oil may become apparent by oil overflowing from the oil vents and breather lines. Particular attention should be given the oil sump if the engine has not been run for several days as the oil may, in certain installations, drain from the tank into the sump and fill it up. As soon as the engine starts, all of this oil in the sump is put back into circulation and may cause damage to the oil system.

5. Securely replace the oil cap. If there is a vent in the cap, make sure that it is open.

6. Wipe off any oil that may have been spilled and be sure to remove all rags, funnels, tools, etc.

7. Replace and safety any cowling that may have been loosened or removed.

8. Make a note of the amount and kind of oil added and the date. This note should be given to the pilot or placed in the cockpit.

Changing Oil - The oil is usually changed at intervals of twenty to fifty hours of flying. The oil change periods may be longer or shorter, depending upon the size of the engine, type and amount of oil carried, and whether or not a filter is installed. For instance the oil may be used thirty hours if a large quantity is carried. Strictly from the standpoint of lubrication, it might not be necessary to change oil as frequently as this. However, the oil change period affords an excellent opportunity to inspect the condition of the oil for any indication of impending engine trouble. It is with this in mind that the following outline is presented.

1. In order to insure faster and more complete oil drainage, the oil should first be warmed. The best way to do this is to run the engine until the proper temperature is indicated by the gage. This usually takes from five to ten minutes. If it is impractical to run the engine, the oil may be heated by an electric immersion heater. One or the other of these methods must be used in cold weather. In warm weather heating the oil is not essential, but it is highly desirable.

2. Make preparations to catch the oil by cleaning all equipment to be used and providing a clean receptacle for the drained oil. There are many places around an airport where old cylinder oil may be used if it is kept clean. More important, the drained oil, if kept clean, may be inspected for sediment and other foreign matter. See #4.

3. Drain the oil by removing the oil drain cap or by opening the oil drain cock, as the case may be. The majority of modern airplane engine installations are provided with a drain from the oil system to the outside of the cowling. If not, it is well to improvise a suitable drain, using a rubber hose, funnels, etc., so that the oil will not spatter or be blown on the ship.

4. It is important to inspect the oil that first comes out of the system, especially if it is drained from the sump. Catch a small quantity of the oil in a clean can. Inspect this to see if any water globules are present. Rub the oil between your fingers. If any grit is felt try to determine if the grit is carbon, sand, dirt, or particles of metal. Any foreign matter in the oil may indicate serious trouble. Babbitt probably means bearing trouble, aluminum would indicate a scored piston, melted wrist pin keeper, chipped housings, etc. In any case, report immediately such evidences of trouble. It

is an excellent procedure to drain the oil through a fine screen or piece of wire gauze. Any dirt or foreign matter will then be trapped by the screen and make it unnecessary to feel the oil with the fingers.

5. After most of the oil has drained out, the oil strainers should be cleaned. Specific directions for cleaning the strainers cannot be given as the types as well as locations vary greatly. If the strainers are in the engine they are usually located near the oil pump or near the oil inlet and outlet. A complete discussion of oil strainers will be found in the chapter devoted to lubrication.

Some oil strainers are located between the engine and the oil tank, on the outlet side. These, of course, are cleaned and inspected in the same manner.

6. Replace and safety all strainers.

7. When the oil has been thoroughly drained out of the system, close and safety the drain.

Caution: It is important that the system be filled promptly after the drain has been closed. This will eliminate the possibility of forgetting it or of someone starting the engine with no oil. If it is imperative to leave the ship with no oil for a period of time, a large sign saying "No Oil" should be tied to the switch or throttle.

8. Refill the oil system with the correct amount and grade of oil. Use no "freak" brands unless so ordered. Take every precaution to keep water and dirt out of the oil.

9. Wipe off any oil which has been spilled, preferably with a gasoline-soaked rag. Remove all rags, funnels, tools, etc.

10. The job should not be considered complete until the engine has been run and the system checked for leaks.

LIQUID COOLING SYSTEMS

The majority of modern liquid-cooled engines are designed to use a high temperature coolant. A mixture of 50% ethylene and 50% di-ethylene glycol is recommended for this purpose. When using this mixture, engines are run at about 250° F. and the radiators are smaller than in water-cooled installations. This means that it should be definitely ascertained, particularly in warm weather, whether the system is designed for water or for the high temperature coolant. If for the latter, water cannot be used, as, due to the smaller radiator capacity, the water will boil out.

If water is used in the system, the filler caps should be vented, whereas if the ethylene glycol mixture is utilized, the system must be closed with no vent, since this liquid is very hygroscopic. When the system is of the closed type, a relief valve, set at 3 to 5 lbs. must be provided. This relief valve must be regularly checked to see that it is functioning. In addition to the relief valve, a check valve is installed in the top of the expansion tank. The check

valve must also be frequently examined to see that it is clear, as if it becomes clogged, the contraction of the liquid while cooling will create a vacuum which may collapse the tank.

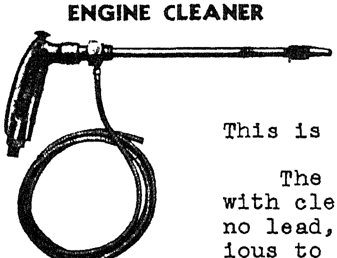
The cores of the radiator must be regularly checked to see that they are not plugged with dirt or insects. The system should periodically be flushed out with clean water or a mixture of water and Oakite.

In cold weather, a suitable anti-freeze mixture should be used in systems designed for water. A table, giving the proportions for such mixtures will be found at the back of this book.

CLEANING THE POWER PLANT

Cleaning the power plant is a very important job and should be done systematically and thoroughly. Cleaning the power plant means more than merely removing the dirt and grease and washing the parts. In addition to this, it affords an opportunity for a thorough inspection of all external parts and accessories.

ENGINE CLEANER



Before cleaning the power plant the cowling should be removed and washed with gasoline and placed aside to dry. All cowling fasteners should be placed in a suitable container to prevent losing them. This is a small item but it is important.

The engine and its accessories should be cleaned with clean gasoline, preferably gasoline containing no lead, as the lead contained in gasoline is injurious to the hands. The cleaning should be started at the top of the engine and proceed downward.

One satisfactory method of cleaning is to use a clean, stiff-bristled paint brush and gasoline. Kerosene may be used, but it is not quite as good for this purpose as gasoline. All grease and oil accumulations should be removed and the surface underneath thoroughly cleaned. If there appears to be an excess of grease or oil on any part, that part and all surrounding parts should be inspected to locate the cause for the excess. This condition may indicate a cracked crankcase, leaking oil line, loose cylinder, loose pushrod housing, damaged accessory gaskets, etc., which, if neglected, may lead to serious trouble.

Gasoline is very detrimental to rubber and for this reason no rubber hose connections should be cleaned with gasoline. If the installation makes it impossible to clean the engine without wetting the hose connections, they should be wiped dry with a cloth as soon as possible. Never get an excess of gasoline on the magnetos, as the gasoline may run inside the magneto and wash off the protecting and lubricating oil and grease. The best method is to use a cloth dampened with gasoline and wipe the magnetos clean. Always inspect the magneto couplings and ground wires while cleaning the magneto.

Where air pressure is available the best method for cleaning is to use a gasoline spray gun, using from 50 to 150 pounds of air

pressure. A gasoline spray not only speeds up the cleaning but it makes it possible to clean in small, hard to clean places such as the cylinder flanges, behind engine accessories, etc. Caution: If a gasoline spray gun is used the battery must first be disconnected. A serious explosion may result if the metal spray nozzle should accidentally short-circuit a battery circuit.

After the cleaning and inspection is complete all control arms and moving parts should be re-oiled. If the airplane is in service around salt water or in any locality where the parts are likely to oxidize easily, the entire power plant installation may be sprayed lightly with a mixture of kerosene and cylinder oil. This may be done with a hand pump insecticide spray gun.

INSPECTION PRIOR TO STARTING

Before attempting to start the engine there are many items that must be carefully inspected to insure its safe operation and the satisfactory completion of the intended flight. Very often the engine mechanic becomes so familiar with the starting procedure that he tends to overlook some of the items. This is a natural tendency but must be guarded against, since the proper functioning of the power plant is the most important single factor where safety in flying is concerned. The following inspection routine is necessarily general; however, in its broader sense it can be applied to any aircraft engine in any installation.

(1) Check the gasoline in each tank. The pilot should be consulted as to the quantity needed for the flight. The gasoline should be measured with a clean, graduated stick while the ship is on level ground. This may seem unnecessary if the airplane is equipped with gasoline gages, but it is such an important item that the gages should not be trusted. Measuring the gasoline not only definitely establishes the amount on board, but also serves to check the accuracy of the fuel gage.

(2) Replace all gasoline tank covers and see that they are securely in place. Be sure that all gasoline tank vents are open.

(3) Remove, clean, replace and safety the main gasoline strainer. Then turn on the main fuel lines and pump up pressure, as previously described, to make sure there are no gasoline leaks in the strainer.

Judgment should be used with respect to this item. If the plane is making a series of short hops the same day, it is, of course, not necessary to drain the strainer between each flight. However, it should be done at least once or twice a day if the plane is doing any appreciable amount of flying.

(4) See that the oil tank is filled to the correct level with the proper grade of oil. If the mechanic is not familiar with the previous operation of the airplane it is advisable to ascertain from the log book how many hours the oil has been used, and if necessary, consult the pilot about changing the oil.

(5) See that all oil caps are fastened securely, and that vents are open, unless vents lead into crankcase.

(6) If the engine is liquid-cooled, check the level of the cooling medium and secure all caps, covers, etc.

The cooling system pump should be checked for leaks around the gland nut and the entire external cooling system should be at least looked over, whenever there is an opportunity.

(7) Inspect all engine and nacelle cowling to see that it is properly fastened and has no bad cracks.

(8) Remove all tools, rags, etc., from the airplane. Inspect to make sure that there are no open or unfinished jobs on either the airplane or power plant. This illustrates the importance of placarding all unfinished jobs.

(9) Check the operation of all engine controls, including that of the throttle, the mixture, spark advance and retard, shutter controls, hot spot, wobble pump and any other controls which may be installed.

(10) Inspect all visible portions of the exhaust manifold, especially if any flexible tubing is used.

(11) Make sure that the propeller or propellers are secure on the crankshaft and that the plane is in such a position that the propellers are free of any obstruction. Papers, rags, small tools, ropes, etc., must be removed to a safe distance from the propeller as they are sometimes picked up and drawn through the propeller, often with serious damage resulting. If a propeller spinner is installed check for proper fastening.

(12) Before starting an engine in an airplane with which you are unfamiliar, inspect the ground wire connections to the magnetos to see that they are tightly in place. This may appear to be an unnecessary precaution, but many accidents have occurred from neglecting it.

(13) If the temperature of the air is much less than 40° F., it may be necessary to pre-heat the engine. See "Cold Weather Starting."

STARTING AND WARMING UP

OPERATION OF VARIOUS TYPES OF STARTERS

The principles, construction and maintenance of starters are discussed in a later chapter. The following instructions pertain purely to their operation while starting the engine.

There are six types of starters which may be operated from the cockpit or from some other point behind the propeller. In addition, there is the "booster" magneto, a complete explanation of which will be found in the chapter devoted to Ignition. Where no booster nor starter of any type is provided, the engine may be started by "pulling the prop" by hand. Fortunately, this procedure has been discontinued in all but the smallest airplanes, since it is highly dangerous and should be attempted only after considerable practice on a dead engine and under the supervision of an experienced mechanic. A modification of hand starting, which is much safer, is the use of an elastic cord, which will be explained in subsequent paragraphs.

Pulling the Propeller - Caution: Never attempt to start an engine in the manner about to be described with an inexperienced person in the cockpit, or while wearing an unbuttoned coat or other loose clothing, or when the ground is muddy, slippery or uneven. If the engine is hot, use extreme caution in moving the propeller, as a hot engine may start with the switch OFF. The need for experience before attempting this operation with a live engine is again emphasized.

Under no circumstances should the engine be started by pulling the propeller without blocks under the wheel, regardless of whether the ship is equipped with brakes or not. After the engine has been primed and the charge sucked in by turning the propeller, with the switch OFF, one blade is set so that the trailing edge may just be reached with arms extended over the head. In taking hold of the propeller, only the tips of the fingers should be over the edge, so that if the engine fires backward, no injury will result to the mechanic. If the blade is caught at the second joint of the fingers, it may be difficult to release in case of a back-fire, and the mechanic may be dragged into the path of the propeller or at the least, have all the skin pulled off his fingers.

Having taken hold of the propeller in the proper manner, the person who is pulling it shouts "Contact" to the pilot or mechanic in the cockpit, who turns the switch on and replies "Contact." When starting in this manner, the faster the propeller is pulled, the more likely the engine is to start, since the intensity of the spark is governed by the speed of the magneto. In order to "spin" the propeller vigorously, the right leg is lifted and moved across the left leg, parallel to the path in which the propeller rotates. The right leg is then swung down and back and at the same time the weight of the body is thrown downward on the propeller blade. If the movement is performed correctly, the swing of the leg will throw one backwards and out of reach of the blades.

In the case of a large engine, two, or even three men may be needed. The propeller is set so that one of the blades is about 45° ahead of its lowest position and the men link hands, each grasping another's wrist. Before taking hold of the propeller, the men swing their bodies, twice in unison, meanwhile counting "One; two ...".

On the count of "three" the man nearest the propeller grasps it with his free hand (the left, in the case of all American engines), and all three pull vigorously, meanwhile running in the direction in which the propeller is being pulled. The man who has caught the propeller is thus dragged out of harm's way by the other two.

A highly satisfactory device for starting large engines consists of a boot made of heavy leather, and of such a size as to fit loosely over the end of the propeller blade. Around the open end of this boot and sewn securely to it, is a piece of heavy shock-absorber or elastic cord, fifteen to twenty feet long and provided with a loop on the free end. To use this device, the propeller is set in an approximately horizontal position, and the boot is slipped over the end of the blade which is to the left of the pilot. The propeller is held in position by an experienced mechanic. The free end of the shock-absorber cord is attached to a truck and the truck then driven away from the airplane, to the right of the pilot, until the cord has been stretched from two to three times its normal length. The mechanic who is steadying the propeller gives the usual signals of "Contact" to the pilot and pulls the propeller a few inches in the direction of normal rotation, taking care to stand clear. The contraction of the cord then pulls the propeller through approximately half a revolution, at which point the boot flies off. The momentum of the propeller carries the engine through several revolutions. This arrangement is illustrated in Figure I.

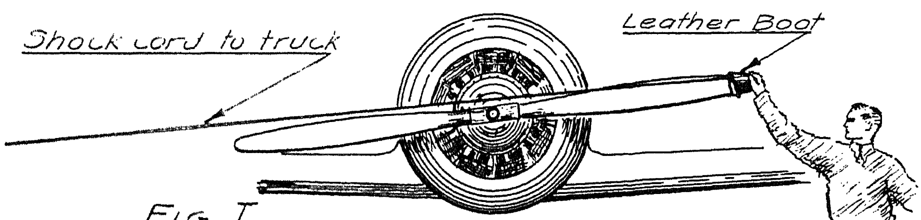


FIG. I

Very small engines, such as the Aeronca, the four-cylinder Continental, the 50 h.p. Menasco, and others of the same type may frequently be started while standing behind the propeller. This method is essential in seaplanes which are afloat, in which case the person starting the engine usually stands on the deck of the right float, holds on to the structure of the airplane with the left hand, and pulls the propeller with the right hand. However, it is entirely possible to stand on the left float and push the propeller upward. This latter method is not recommended for inexperienced persons.

Engines of the class just mentioned, and others up to about 100 h.p. are frequently provided with an impulse coupling on the magneto. The presence of such couplings is indicated by a loud click as each cylinder passes the firing point. When this device is installed there is no advantage in pulling the propeller violently, in fact, better results are obtained if it is pulled as slowly as possible consistent with keeping clear.

The Booster Magneto or Coil - This device simply produces a hot spark in the cylinder regardless of whether the regular engine magneto is turning or not. It utilizes the distributor and external

wires of the main ignition system, but not the other parts. If the booster is of the magneto type it may be cranked by the pilot. If a coil and battery type is installed, the spark is produced simply by pushing a button. The booster may be used in conjunction with any of the starters previously discussed, to intensify the spark, or it may be used alone. In the latter case, the engine is properly primed by turning the propeller, the switch turned on, and the booster operated. Since the spark produced by the booster occurs when the piston is past top center, there is no danger of the engine "kicking" or starting backwards. After starting, the booster should be kept in operation by continuing to crank the magneto or by holding the push button down until there is no doubt that the engine will continue to run.

The Direct Hand Crank - On engines of 300 h.p. or less, a type of starter sometimes used consists of a hand crank geared directly to the crankshaft, with no mechanism other than a set of reduction gears. Sometimes a booster magneto is built into the mechanism so that a hot spark is produced in the cylinder in spite of the fact that the engine is being turned very slowly. Operation of this starter consists simply of turning the crank as rapidly as possible until the engine starts. If the starter is provided with an integral booster, it is advisable to continue spinning the crank thus continuing the booster spark, until it is evident that the engine will keep on running on the sparks from the main ignition system.

The Air Injection Starter - This type of starter was once extremely popular but has been largely superseded by other varieties. It is operated by feeding compressed air to the cylinders through a valve controlled by a T-handle in the cockpit. This handle is turned a quarter of a revolution to the left to unlock it, is pulled out, and as soon as the engine starts, is pushed back in and rotated a quarter-turn to the right to lock it and prevent accidental operation. If the engine does not start immediately, the handle should be pushed in and the reason for the failure to start determined, for if the starter is operated continuously for more than a few seconds, the air will quickly become exhausted. It will then be necessary to start the engine by swinging the propeller or by some other means.

The Combustion Starter - This starter is operated by the explosion of a charge of powder contained in a cartridge. The cartridge is placed in a breech in the cockpit and exploded by making an electrical contact through a push button switch. Before attempting to use this type of starter, the details of its construction and use, as discussed in the chapter on Starters and Generators, should be studied.

The Inertia Starter - The principle of the inertia starter consists of storing up energy by spinning a heavy fly-wheel, which is then connected to the engine by means of a clutch. The momentum or inertia of the spinning wheel then turns the engine over several revolutions until the energy is used up. In the hand inertia starter the fly-wheel is spun by means of a crank, which may be attached to a series of gears connected to the fly-wheel. The crank is turned, slowly at first, increasing the speed to the maximum possible. It is then quickly pulled off the shaft and the clutch engaged by means of a handle located either in the cockpit, or within reach of the

person turning the crank. In some installations, the handle is arranged so that it is pulled to engage the clutch, in others, it is pushed, the former being the more common. When turning the crank, the operator should be careful to have a good footing, or to hold to some solid part of the airplane with one hand, so that any possibility of falling into the propeller is eliminated.

Many airports are provided with a device known as an External Energizer, for use with inertia starters. The Energizer is simply a motor, arranged so that it may be connected to the shaft of the starter. Current for the motor is supplied by batteries outside of the airplane. This device naturally eliminates any effort on the part of the mechanic. It is discussed more fully in the chapter on Starters and Generators.

The Electric Inertia Starter - This starter is identical with the type just discussed except that it is provided with an electric motor built into the starter and operated by means of batteries carried in the aircraft. The control is almost invariably in the pilot's cockpit and consists of a button or handle which is pushed to start the electric motor and pulled to engage the clutch. To start the engine, the button is pushed for five to ten seconds, or until the starter has reached its maximum speed as judged by the whine of the gears. The button is then pulled. In case the battery is weak, the electric inertia starter may be operated by hand crank just as though no motor were provided.

The Direct Electric Starter - This starter needs practically no explanation since it is operated exactly as the starter of an automobile; in other words, simply by pushing a button with either the foot or the hand. The direct electric starter is usually provided with a means for attaching a hand crank, by which the engine can be turned through reduction gears in case the battery is run down.

STARTING IN NORMAL WEATHER

The procedure in starting varies somewhat with different types of engines and even to a slight degree with individual engines of the same type. However, the rules given below will, in general, be found satisfactory.

(1) Head the ship into the wind, see that the propeller is clear of obstructions and that the slipstream will not blow on other airplanes or into the hangar, and block the wheels.

(2) Check the ignition switch to see that it is OFF.

(3) If the propeller is of the two-position controllable type, set the control to the high pitch position. If a constant speed, Lycoming-Smith, or Curtiss Electric propeller is being used, set the control to the low pitch position.

(4) Close the throttle, set the mixture control to the full rich position and advance the spark. Note: Some engines show a tendency to kick back when started with the spark fully advanced. If this tendency is evidenced, retard the spark about half way until the engine fires and then immediately advance it.

(5) Turn the gas shut-off cock to the ON position. Turn exhaust analyzer ON. Set manifold pressure regulator to Take-off position and close oil cooler or radiator shutters. Note: The last three items of equipment are usually not installed on the smaller ships.

(6) If the fuel system is of the pressure type, operate the wobble pump until the pressure gage indicates 5 or 6 lbs./sq.in. Caution: Do not continue operating the wobble pump if the carburetor begins to drip, as this causes an unnecessary fire hazard.

(7) If the engine is cold, turn the primer shut-off cock to the ON position and prime with five or six strokes of the priming pump. The pump handle should be pulled back slowly and a slight pause made when the plunger is fully extended, so as to give time for the gas to be sucked into the pump, then pushed in quickly to atomize the fuel. Turn the cock OFF after priming. If the engine is warm, no priming is needed. Note: Some of the smaller engines are equipped with a choke instead of a priming pump. These engines are primed by pulling out the choke and turning the propeller forward two or three revolutions.

Some engines use carburetors provided with an integral primer which utilizes the accelerating pump of the carburetor for priming. To operate, set the mixture control lever in the full lean position and pump the throttle three or four complete strokes. Then return the mixture control lever to the full rich position and pump pressure into the carburetor before starting.

(8) Having operated the priming pump, turn the propeller forward several revolutions by hand. Manual operation at this point is extremely important for two reasons. In the first place, there is sometimes a leakage of oil into the lower cylinders. If one or more cylinders are partly full of oil and the starter is used, serious damage, such as broken cylinder heads, broken pistons, or bent connecting rods, may occur. In the second place, turning the engine by hand with the switch off begins the lubrication of the cylinder walls before the engine starts running and furthermore if a direct electric starter is used dispenses with an unnecessary drain on the battery.

(9) Set the carburetor heat control in the "cold" position, so that a possible back-fire will not damage the induction system.

(10) Open the throttle slightly - approximately one-tenth of its full throw, pull elevator control hard back, apply brakes.

(11) Call "CLEAR", and see that no one is near the propeller.

(12) If the starter is of the direct electric type, push the starting button, allow the engine to turn over one or two revolutions and turn the ignition switch to the "BOTH" position. Note: These instructions assume that the engine is equipped for magneto ignition. If the ignition system is of the battery type, turn the switch to the retarded distributor. It will be necessary to learn from someone familiar with the installation whether this is the left or the right. If any other type of starter is used, turn the switch first, then operate the starter. If the propeller is being pulled by

hand, wait for the person pulling it to call "Contact", then turn the switch on. If both a starter and s booster are provided, use the booster while the engine is being turned by the starter.

(13) If it still refuses to start, open the throttle wide and turn the propeller forward three or four revolutions by hand. (Note: In the case of a seaplane floating in the water, the propeller must naturally be turned by the starter instead of by hand.) Having thus cleared the engine, attempt to start it without repriming and if unsuccessful, begin once more, using less prime than on the first occasion. If this attempt fails, an inspection should be made to determine the source of the trouble, as outlined in the chapter devoted to "Engine Troubles."

Summary of Engine Control Settings

(1)	Fuel Supply Cock...............	"ON"
(2)	Ignition Switch................	"OFF"
(3)	Throttle.......................	Set for 700-800 r.p.m.
(4)	Mixture........................	"RICH"
(5)	Propeller (Constant Speed).....	"LOW PITCH"
	" (Two Position).......	"HIGH PITCH"
(6)	Carburetor Air Heater..........	"COLD"
(7)	Manifold Pressure Regulator....	Set for take-off pressure
(8)	Oil Cooler Shutter.............	"CLOSED
(9)	Exhaust Gas Analyzer...........	"ON"

COLD WEATHER STARTING

When the temperature is below 40° F., the oil must be heated in some manner prior to starting. If the oil has been drained, it may be heated by placing it on a stove, or by applying a blow torch to the outside of the can. If it is in the tanks, it will be too cold to drain and an electric immersion heater such as that shown in Fig. I must be employed. The engine should be turned over fifteen or twenty revolutions with the switch off after the oil has been heated and before priming, so as to start the warm oil flowing through the interior.

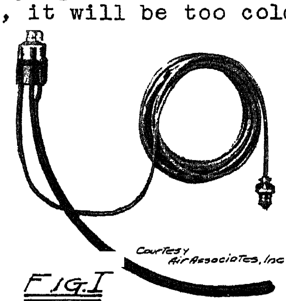


FIG. I

In temperatures lower than 10° F. it is highly desirable to heat the entire engine by means of a canvas engine heater. See Fig. II. This device consists of a cover which encloses the engine and which is provided at the bottom with a large tube of fabric leading down to and enclosing a small oil stove. The oil stove is lighted half an hour or more before the engine is to be started. The heat from the stove is held close around the engine by means of the canvas hood, and warms all parts of the engine. However, this device does not heat the oil which is in the tanks and is used simply as an adjunct to the oil heater mentioned in the preceding paragraph. Needless to say, the gasoline should be shut off and there must be no leakage from the carburetor when an engine heater of this type is used.

More priming is needed than in warm weather and the priming pump should not be turned off until after the engine is actually

running, as it is frequently helpful to give the pump three or four slow strokes immediately after the engine has started.

FIG. II

Cold weather starting may often be facilitated by removing the spark plugs and warming them. Probably the simplest method of accomplishing this is to stand the plugs with the terminal end down and fill the shell with gasoline. Ignite the gasoline and let the plugs burn dry. Replace them as quickly as possible and crank the engine immediately.

If additional priming is needed, the spark plugs may be removed and a few drops of gasoline poured into each cylinder. Note: This should be done sparingly as the gasoline washes the oil from the cylinder walls, and using it too freely may cause the piston to "seize". In extreme emergency, a mixture of 50% ether and 50% gasoline may be used instead of straight gasoline. A few drops of this mixture should be squirted into each spark plug hole by means of a small oil can. However, it is highly explosive and should be resorted to only when everything else has failed, and then not without the supervision of an expert mechanic.

WARMING UP

Note: The smaller ships frequently do not have some of the adjustments mentioned below. In such cases, the instructions pertaining to those items are naturally not applicable.

(1) As soon as the engine has definitely started, note the oil pressure. If, after a few seconds, less than half of the normal running pressure is indicated, the engine should be shut off and the source of the trouble ascertained.

(2) Manipulate the throttle to obtain from 600 to 800 r.p.m. Great caution should be observed with respect to "pumping" the throttle, as an excess of gas will overflow from the carburetor and constitute a serious fire hazard.

(3) Set the carburetor heat control to the "hot" position, particularly in cool weather.

(4) After the engine has begun to run smoothly open the throttle to give 800 to 1,000 r.p.m.

(5) Set propeller to the low pitch position (if it is not already there).

(6) Continue to run at 1,000 r.p.m. until the oil inlet temperature begins to rise, as indicated by the oil thermometer. (The

various power plant instruments will be discussed in detail in a later chapter. Since the function of each instrument is plainly marked on its dial, a further explanation is not considered necessary at this time.)

(7) Increase engine speed to 1000 - 1200 r.p.m. and run until the oil temperature is not less than 60° F. and preferably until it has reached 100° F. However, in extremely cold weather an increase of 10° F. above the starting temperature is considered satisfactory.

Note: Some thermometers are calibrated in the centigrade scale. Conversion tables will be found at the back of this book.

(8) Open throttle to specified cruising manifold pressure and r.p.m. long enough to check each magneto (by turning the switch first to one and then to the other) and the fuel and oil pressures. If the oil pressure drops when the throttle is opened, it is an indication that the engine is not warm enough and the speed should be brought back to 1,200 until the oil temperature has been increased. In testing the magnetos, when the switch is turned from "BOTH" to either one, the drop in r.p.m. should be not more than 75. Check operation of propeller pitch control.

(9) Having completed the checks outlined in the preceding paragraph, the throttle is closed to the idling position and the ship is ready for take-off. If the take-off is not to be made immediately, the engine should be shut off in accordance with instructions under "Flight Operation."

FLIGHT OPERATION

It is impossible to lay down a definite set of rules for the flight operation of all engines. It may readily be understood that a 40 h.p. Aeronca engine is handled very differently from a 1,500 h. p. Wright Cyclone. There is a variation even in the operation of engines of approximately the same size but built by different manufacturers. Accordingly, it is highly desirable that the pilot or flight mechanic study the flight instructions in the handbook of the particular engine which he is using and follow them implicitly, for, after all, the manufacturer of the engine probably knows more about it than anyone else and is certainly more interested than anyone else in having it perform satisfactorily.

On the other hand, there are certain general rules of operation which are applicable to any engine and, in addition, certain other practices which are followed with various engines of the same general type. From the standpoint of flight operations engines may be roughly divided into three general classifications: those of less than 200 h. p., which may be called small engines; those of 200 to 400 h. p., or medium-sized engines; and those about 400 h. p., which may be considered as large engines. The last group may appear to cover an extremely wide range, since some of the large engines develop around 1,500 h. p. However, the first group is usually installed in small sport planes which are not ordinarily provided with elaborate instrument equipment; these engines, furthermore, are practically never supercharged. The second group from 200 to 400 h. p. are installed in the larger sizes of privately owned planes, such as the Stinson, Waco, Beechcraft, etc. They may or may not be supercharged, but even if a supercharger is installed, its gear ratio is usually low enough to permit full throttle operation, temporarily at least, at sea level. Engines of more than 400 h. p. are almost invariably supercharged and are usually installed in transport, military, or very expensive private airplanes. In such airplanes the instrument equipment is usually much more comprehensive and also there are usually many more engine adjustments provided for. Accordingly, instructions for flight operation will take into consideration the general class to which the engine belongs.

SMALL ENGINES

It is assumed that the engine has been warmed up according to the instructions in the preceding pages. On the smaller engines, the propeller is usually of the fixed pitch type and hence requires no adjustment. When ready for take-off, the ship should naturally be at the extreme edge of the down-wind side of the airport and facing into the wind. It is probable that a certain period of taxiing has been required to get the ship into this position. If such is the case, it is desirable to recheck the engine prior to taking off, for both idling and full throttle conditions. The reason for checking the idling is that in taxiing over a rough field, sediment in the carburetor may be loosened and may then possibly clog the idling jet. If this jet becomes plugged, it means that the engine will probably stop when the throttle is closed for the glide, prior to landing. Such an occurrence might cause trouble in case the engine were needed to correct a bad landing or if some obstruction, such as another ship taxiing across the runway, made it necessary to continue flight before the landing were completed.

An extended period of comparatively slow running may tend to foul the spark plugs or "load" the engine so that it will not function satisfactorily at full throttle. For this reason, the full throttle operation should be checked before taking off. Prior to this final check the position of the spark and mixture controls should be noted. The spark should be fully advanced and the mixture at the full rich position. Also the position of the gasoline shut-off valve should be checked to see that it is fully opened, and on the proper tank if more than one tank is installed. With the stick held hard back and the brakes locked, the throttle should then be opened smoothly to its fullest extent, the magnetos tested, and the readings of the power plant instruments noted. If there are no ships coming in for a landing and the control tower operator gives the take-off signal, the brakes may be released without closing the throttle and the ship allowed to take off.

As soon as any obstructions around the field have been cleared, and in any case within one minute after taking off, the throttle should be pulled back until there is a drop of at least 50 r.p.m. while the ship is still climbing. After the desired cruising altitude has been reached, the airplane is levelled out and the throttle closed further until the engine is turning at the cruising r.p.m. recommended by the manufacturer. In most cases this will be about 90% of the rated r.p.m. If thermocouples are provided, the temperature of the cylinder heads should be checked to see that it is within the limits specified by the engine manufacturer. In most cases, the maximum permissible head temperature is 500° F. for one minute during take-off and 450° F. for cruising. The maximum cylinder barrel temperature is usually in the region of 350° F. At least once every two or three minutes the oil pressure and oil temperature should be noted. The oil temperature should remain above that specified by the manufacturer, usually in the neighborhood of 70 lbs./sq. in. If the pressure should at any time drop appreciably a landing should be made at the first convenient opportunity. If it falls below 30 lbs./sq.in. the ship should be landed as quickly as it can be done safely, since there is a great possibility that engine failure will shortly occur. The oil temperature should not exceed 180° F. If it runs above this figure, a landing should be made as soon as practicable. Oil temperature and cylinder head temperature may often be decreased by reducing the r.p.m. below that normally used in cruising but keeping it high enough to maintain satisfactory flying speed. If a generator is installed the reading of the ammeter should be occasionally noted. If it shows a discharge, the electrical system should be checked at the next airport, particularly if battery ignition is being used.

The fuel system in ships of the size being discussed is usually of the gravity type and no fuel pressure gage is needed. If the system is of the type which uses an engine-driven fuel pump, the reading of the fuel pressure gage should be noted frequently. This should be, in most engines, about 5 or 6 lbs./sq.in. In temperatures below freezing the carburetor heat-control should be used, particularly during the take-off and first part of the flight. The temperature at which this control is necessary varies to some extent with the engine installation, but when flying in clouds or rain, the heat should be used if the air temperature is below 70°. Perhaps the best method of determining whether the heat should be turned on or not in

clear weather is to note how the engine behaves with the heat on and with it off. The position of the heater which produces the smoothest operation should be used in cold weather. However, under no conditions should the heater be used in warm weather, as overheating and consequent injury to the engine is likely to result.

If the ship is equipped with a mixture control, it should not be used under 5,000 ft. in any case. Some manufacturers advise against leaning the mixture below 10,000 ft. Here, again, the engine handbook should be consulted. However, in general, there are two procedures recommended for determining where to set this control. One of these consists of leaning the mixture without moving the throttle until the r.p.m. will not increase further. This may be at a point about 50 r.p.m. higher than the engine was turning before the mixture was changed. Having attained this maximum excess r.p.m., the throttle is then closed until the r.p.m. is reduced to its original figure. The other procedure consists of leaning the mixture until the r.p.m. drops below its original figure and then richening it again until the initial r.p.m. is restored. The smaller airplanes are seldom equipped with exhaust gas analyzers or automatic mixture controls. These will be discussed more specifically in the instructions pertaining to the larger engines.

The handling of the engine when a landing is to be made may have a pronounced effect on its maintenance and total life. When descending from altitudes above 1,000 ft., it is highly desirable to leave the throttle partly open. This may not give a student much opportunity to judge "spot" landings, but will prevent the engine from cooling off too rapidly, with possible valve warpage or other damage, particularly in cold weather. The throttle should be closed until the r.p.m. is approximately 1,500 during the glide. The mixture control should be in the full rich position. When an altitude of less than 1,000 ft. has been reached, the throttle may be closed still further and when the 500 ft. mark has been passed, it may be closed entirely. For the remainder of the glide, it should be smoothly and gently opened about half way every ten or fifteen seconds, so as to keep the engine "clear" and warm enough to "take" again in case something interferes with the landing. This smooth and slow movement of the throttle is quite important. In the first place it eliminates unnecessary abuse caused by abruptly increasing the r.p.m. In the second place, in most carburetors, slamming the throttle open pumps extra gas into the induction system. This may actually foul the motor instead of clearing it, thus defeating the purpose of the procedure.

Closing the throttle tends to make most airplanes nose-heavy. Due compensation should be made for this condition with the stabilizer adjustment. However, in some airplanes, the use of the flaps offsets this nose-heavy condition and renders the stabilizer adjustment unnecessary for landing.

A gentle glide is desirable because the engine is not cooled off so rapidly. Furthermore, it is extremely difficult to make a good landing if the approach is too fast. Side-slipping is also likely to be detrimental to the engine if not completely cowled or if short stacks are used instead of an exhaust ring or manifold.

This is particularly true in the case of line engines, as a side-slip tends to blow cold air into the exhaust pipes and directly upon the hot exhaust valve. Obviously, the steeper the slip and the lower the forward speed of the airplane, the greater the effect upon the valves. However, most modern ships provide complete cowling and exhaust manifolds, so that this point is not of great importance.

The opinions of different manufacturers vary with respect to the procedure followed in shutting off the engine. However, the following will, in most cases, be found to be satisfactory: After the airplane has been taxied to the position where the engine is to be shut off, the throttle is closed and the engine allowed to idle at, or near, its lowest idling speed until the cylinder head temperatures have dropped to 300° - 350° F. The switch is then turned off and the gasoline shut-off cock turned to its closed position. If there is "after-firing" turn the switch on again immediately and allow the engine to cool still further. In the case of a seaplane, it may become necessary to shut off the engine while the ship is moving through the water. To eliminate the possibility of after-firing, the airplane should be taxied very slowly for several minutes before turning off the ignition. If the engine continues to kick over it may usually be stopped by opening the throttle wide after the switch has been turned off. After-firing is ordinarily caused by hot carbon in the piston or cylinder head, or by the cylinder head itself being extremely hot. Opening the throttle abruptly with the switch off causes a large amount of cold air to be sucked into the cylinders so that the temperature of the heated parts is reduced below the point where combustion will be caused. Furthermore, the period of slow idling tends to cover the cylinder walls with oil which is cooled sufficiently, especially when the throttle is opened as described, to prevent its running off. This insures adequate lubrication when starting the engine again. Careful treatment in shutting off an engine is almost as important as proper warming up when starting.

MEDIUM-SIZED ENGINES

Practically all of the operating rules given for the smaller engines also apply to engines of this medium class. However, there are additional items to check. In the first place, many of the ships in which these engines are installed are equipped with controllable-pitch propellers of one type or another. When such propellers are used they should be set to the low pitch position before beginning the take-off. Some engine manufacturers permit the propeller setting to be such that the normal rated r.p.m. may be exceeded for one minute. Ordinarily this means approximately 200 additional r.p.m. However, the instruction book should be consulted to determine this maximum permissible r.p.m.

Most of the airplanes in which motors of the size under discussion are installed are equipped with manifold pressure gages. If the controllable-pitch propeller is used, this instrument is essential. The maximum permissible manifold pressure is usually noted by marks on the instrument, a card in the cockpit, or both. The limits usually consist of one maximum for one minute after taking off and a lower maximum for cruising. In the case of unsupercharged or sea-level engines, the maximum for take-off is usually in the region of 28 inches of mercury (ordinarily written 28" Hg.). The maximum for

cruising up to 2,000 ft. is around 25" or 26" Hg.; for cruising at 4,000 ft. 23" Hg.; and for cruising above 6,000 ft. 21.5" Hg. However, the proper pressure should be obtained from the engine manufacturer.

After cruising altitude has been reached and the ship has been levelled off, the manifold pressure should be regulated by proper adjustment of the throttle and the propeller pitch if a controllable propeller is used, or by the throttle alone if the propeller is of the fixed pitch type. It may be remembered in this connection that for a given r.p.m., the lower the propeller pitch, the lower will be the manifold pressure. The manifold pressure is the best indication of the load on the engine and many manufacturers permit their engines to be run continuously at the maximum rated r.p.m. provided the manifold pressure is kept within the proper limits. In fact, it is claimed by some that with a given manifold pressure, there is less abuse on the engine at a fairly high r.p.m. with a low pitch propeller, than at a lower r.p.m. with a high pitch propeller. When a manifold pressure gage is installed the tachometer assumes a position of relatively minor importance, provided the rated r.p.m. is not exceeded. The propeller pitch and the throttle setting should be so adjusted as to obtain the maximum airspeed with the permitted manifold pressure.

In engines of this class the instructions for throttling during the landing glide are the same as for the small engines. With respect to shutting off the engine, instructions vary with the make. For example, the manufacturers of the Lycoming recommend that the throttle be closed gradually to normal idling position, the ignition switch cut, and as soon as the engine begins to lose speed, the throttle fully opened. If after-firing occurs, the mixture control is moved to the full lean position. The manufacturers of the Jacobs engine recommend idling the engine for approximately five minutes or until the cylinder head temperature has dropped to approximately 350° F. and then cutting the switch. The Wright Company recommends that their Whirlwind engines be stopped as follows: Close the throttle until the engine is turning about 800 r.p.m. and run at this speed until the cylinder heads have cooled to approximately 300° F. The propeller is then shifted to high pitch and as soon as the r.p.m. begins to drop, the mixture control is moved to the full lean position. This shuts off the gas and the engine will stop firing, after which the ignition switch should be turned to the "OFF" position. The throttle should not be opened to cool off the engine. To prevent possible accidental starting the mixture control should be left in the lean position and the switch, of course, off.

LARGE ENGINES

Engines in this class are almost invariably supercharged and also usually equipped with either controllable-pitch or constant speed propellers. The airplanes are ordinarily provided with all the instruments necessary for proper determination of conditions in the engine. There are thermocouples on the head and base of several cylinders - frequently of all the cylinders - a selector switch being installed so that the temperature of any cylinder head or base may be readily determined. Exhaust gas analyzers and carburetor intake air temperature gages are usually supplied. Carburetors are frequently equipped with automatic mixture control.

Many of the larger engines are designed to develop their full power only at altitude. In these the impeller is turned at a higher speed and the throttle lever is equipped with a stop so that it cannot be inadvertently opened past a certain point. By pressing a release button or some other device of a similar nature, the throttle may be opened the rest of its throw. This should be done only at the proper altitude. Some engines are provided with a two-speed impeller, the low gear ratio being used for low altitudes and the high gear for high altitudes.

On these larger engines the mixture control is extremely important, partly because it exerts a marked effect upon the operation of the engine and partly because, due to the relatively large quantities of fuel which are used, economy of consumption becomes an important item. It should always be borne in mind that improper use of the mixture control, even if for only a few minutes, may completely ruin the power section of an engine. If the mixture is too lean, the engine will over-heat and the pistons and valves will be damaged; if the mixture is too rich, the engine will run rough and will use an excessive amount of gasoline. The Pratt & Whitney Company explains the use and effect of the mixture control as outlined below.

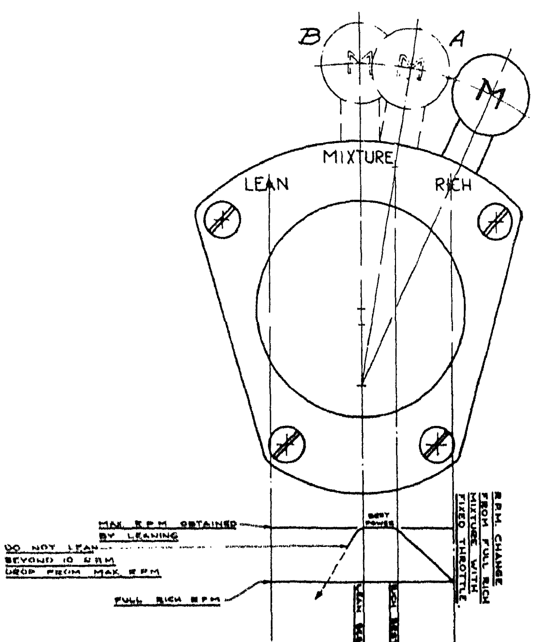


FIG. I

Courtesy Pratt & Whitney Aircraft.

In order to understand the explanation, reference must be made to Fig. I, which shows a mixture control lever and, underneath, a small section of the r.p.m. curve, indicated by the diagonal line. The lower horizontal line in the diagram, marked "FULL RICH R.P.M." indicates the maximum r.p.m. obtained when the mixture control is in full rich position and the throttle at a given setting. By leaning the mixture a certain amount, as indicated by the position of the handle at A, the r.p.m. will increase to a maximum, illustrated by the upper horizontal line. (It must be remembered that the positions A and B of the mixture control handle simply indicate movement and not a definite location of the handle.) Further movement through a limited amount will not decrease the r.p.m. Still further leaning, however, will cause the r.p.m. to drop. The position at which the maximum value is first noted, indicated by A, is called "RICH BEST POWER." The point at which a further movement of the handle results in a loss in the value, indicated at B, is called "LEAN BEST POWER." The range between these two is called

"BEST POWER." The mixture should never be leaned so that the r.p.m. drops more than 10 below the maximum.

The Pratt & Whitney Company recommend that the mixture control be readjusted for each 1,000 ft. change in altitude. For take-off, climb or landing at, or near, sea level, the mixture control should be in the full rich position and also at any time at which more than 75% of the rated power is being taken from the engine. This rule may be violated at extreme altitudes, under which condition the mixture may be leaned just enough to obtain smooth running. At 65% to 75% of rated power the mixture control may be leaned during level flight to "rich best power." Below 65% of rated power the mixture control may be leaned during level flight to "lean best power." However, since there are so many variables in the average flight, the mixture control settings should be checked frequently to make sure that the engine is not running too lean, especially if there is any change in altitude, temperature or throttle setting.

When the engine is equipped with an automatic mixture control the proper mixture is automatically taken care of under most conditions. However, the normal manual mixture control is also installed in case of any failure of the automatic unit. In the full power position the carburetor functions independently of the automatic unit and if it is desired to obtain better fuel economy the manual control may be operated. In the mid-position, the power is limited to a predetermined range and the correct mixture for that range is supplied. The Pratt & Whitney Company recommend that where a constant speed propeller is used, the throttle should be left open and the engine r.p.m. reduced by means of the propeller control. The carburetor air intake temperature must be maintained at 90° to prevent an excessively lean mixture. This mid-position is normally used for climb and in some instances for high power cruising. For normal cruising the cockpit control of the automatic mixture device is moved to the cruising position. Here also the throttle should be left open and the r.p.m. reduced to the predetermined maximum by means of the propeller control, as this obtains maximum fuel economy.

The following instructions are given by the Wright Aeronautical Corporation for the flight operation of their Cyclone engines. In general these instructions will apply also to any of the large radial types.

Take-off - It is important to remember that during take-off and climb, if icing conditions are indicated (by an unwarranted drop in manifold pressure), the carburetor heat control must be adjusted to maintain temperatures as follows:

(a) Stromberg carburetor - mixture temperature of 35° F. (maximum) or intake air temperature of 90° F. (Maximum).

(b) Chandler-Groves or new type Holley carburetor - intake air temperature 35° F. (Maximum).

Before making this adjustment, richen the mixture (if it is not already full rich). Then, after the heat is adjusted, readjust the

mixture in accordance with instructions given under the various flight conditions.

(1) With controls set as specified in the summary at the end of the section on "Warming-Up", open the throttle against the stop. (Do not start take-off with cylinder head temperature above 400° F. or below 250° F.) Note: In case of failure of supercharger pressure regulator, the throttle can be opened full by moving the throttle lever beyond the throttle stop on the quadrant.

(2) After not more than one minute (five minutes in emergency) throttle back to rated or cruising power for climb.

Rated Power Climb - Adjustments (1) and (2) which follow must always be made in the order given, never the reverse.

(1) Adjust manifold pressure to that specified for rated power as follows:

(a) If automatic manifold pressure regulator is installed, use control for same, leaving throttle against stop.

(b) Lacking automatic regulator, retard throttle. With increase of altitude, throttle must gradually be opened until at critical altitude it is fully open.

(2) Adjust r.p.m. to that specified for rated power as follows:

(a) With constant speed propeller, set control at rated r.p.m.

(b) With two-position controllable-propeller, leave in low pitch until r.p.m. is exceeded, then move to high pitch position.

(3) Adjust mixture as follows:

(a) Chandler-Groves carburetor - leave full "RICH."

(b) Stromberg carburetor - lean out until indicator on the exhaust gas analyzer dial coincides with the existing manifold pressure.

Cruising Power Climb -

(1) Adjust manifold pressure to the value specified for cruising using the same procedure as for rated power climb.

(2) Adjust propeller to give cruising r.p.m. using the same procedure as for rated power climb.

(3) Adjust mixture as follows with either carburetor: Lean until indicator on exhaust gas analyzer dial coincides with the existing manifold pressure.

Level Flight at Rated Power - Under icing conditions, adjust carburetor air heat as directed under "Take-off."

(1) Adjust manifold pressure to that specified for rated power as follows:

(a) If automatic manifold pressure regulator is installed, use control for same, leaving throttle control lever against stop.

(b) Lacking automatic regulator, use pilot's throttle control lever.

(2) Adjust propeller as follows:

(a) With constant speed propeller, set control at rated r.p.m.

(b) With two-position controllable propeller set in high-pitch position.

(3) Adjust mixture as for rated power climb.

Level Flight at Cruising Power

(1) Adjust manifold pressure in same manner as for level flight at rated power except adjust to cruising manifold pressure.

(2) Adjust propeller as follows:

(a) With constant speed propeller, set control at cruising r.p.m.

(b) With two-position controllable propeller, set in high-pitch position.

(3) Adjust mixture as for cruising power climb.

Descent for Landing, to About 500' Above Airport -

(1) For descent at rated power, no change in controls from level flight at rated power need be made except that with Stromberg carburetor it is necessary to richen the mixture during descent, and without an automatic manifold pressure regulator it is necessary to close the throttle gradually as required to maintain specified rated pressure.

(2) For descent at cruising power, no change need be made from the setting of propeller control, Chandler-Groves mixture control, or automatic pressure regulator for level flight at cruising power. Lacking an automatic regulator, use the throttle control which must be gradually closed as altitude decreases.

With Stromberg carburetor, richen the mixture during descent.

(3) Under icing conditions, adjust carburetor air heat as necessary to maintain temperatures noted under "Take-off." Always enrich-en mixture before reducing heat.

At 500' Above Airport, Preparatory to Landing -

(1) Move manual throttle control lever gradually toward closed position and set propeller at low pitch or take-off.

(2) Set manifold pressure regulator control for take-off pressure and use manual throttle lever to control engine.

(3) Set mixture control full rich with either type carburetor.

(4) Set carburetor air heater in "cold" position except under icing conditions, when setting is left as for descent.

Caution: If subsequent emergency arises requiring full emergency power, turn control to cold position immediately after opening throttle. Then adjust heat control as necessary to maintain the temperatures noted in the instructions under "Take-off."

Stopping the Engine After Landing -

(1) Idle at 600 - 800 r.p.m. until cylinder head temperature drops below 300° F. (If absolutely necessary to stop engine before properly cooling off, engine should be stopped while running at 1,000 - 1,200 r.p.m.)

(2) Move mixture control lever from full rich to full lean (fuel shut off) position. Engine will stop in a few seconds.

(3) Turn ignition switch off after propeller stops turning.

(4) Turn exhaust gas analyzer off.

(5) Do not move propeller until engine is thoroughly cooled.

CHAPTER 6

CARBURETORS AND INDUCTION SYSTEMS

CARBURETORS

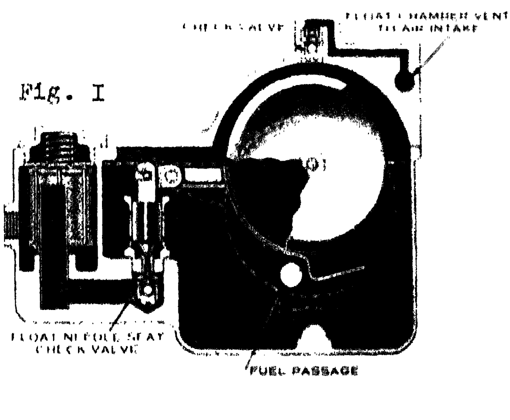
The following discussion of carburetors is written with the assumption that the mechanic understands the basic functions of these mechanisms and their relationship to the engine as a whole. If these functions are not entirely clear it is advisable to review them by referring to Chapter II.

Modern aircraft engine carburetors are designed to be efficient, reliable and compact and as a result they appear to be complicated devices with many intricate passages and elaborate accessories. While it is true that some of the large carburetors do present a formidable appearance they are, nevertheless, easy to understand if the principle and purpose of each division or system is inspected separately to ascertain why it is needed and how it affects the engine. It is impossible to overemphasize the importance of actually understanding the theory of carburetion and not merely the mechanical functioning of one or two types of carburetors. Only by possessing such a basic knowledge can one become an expert mechanic, as it is probable that the proper operation of the engine depends on the carburetor more than on any other single item.

The best way to understand any carburetor is to disassemble it and trace the flow of the fuel from the inlet opening through each of the fuel passages and through each of the systems to its ultimate discharge into the intake manifold. It is often difficult to trace a passage that is drilled through some portion of the body, but by blowing into one end of a passage the other end can be located quickly. This procedure is greatly simplified by using a small diameter rubber tube or a soda straw. If any difficulty is experienced in understanding the action of any part it is sometimes helpful to make a large-scale rough sketch of the part and its relationship to the rest of the system. Then, in attempting to analyze its function, ask yourself the following questions: Does fuel or air flow to the part? How does it get here, where does it go, how does it go, when does it go and what makes it go? Obviously, if you can learn the answers to these questions you will understand the purpose of the part. The carburetor manual should be consulted if available.

<u>Strainers</u> - Even though there are one or two strainers in the fuel line, most carburetors are provided with strainers of their own, which serve as an additional safety precaution to prevent the entrance of any dirt or water. It is essential that all fuel that enters the carburetor proper be absolutely clean, as even the smallest grit or a few drops of water may cause mal-func-

Fig. I



tioning or complete stoppage of the carburetor, often resulting in engine failure.

The strainer system usually consists of a water trap and a filter similar to the one shown in cross section in Fig. I. The filter in this illustration consists of a fine mesh wire covering a cylindrical frame. The screen usually has approximately 120 meshes to the inch, which makes the openings small enough to retard the passage of water but still large enough to admit gasoline readily. This screen also filters out most of the foreign particles that escape the fuel line strainer. The fluid that passes through the screen does not enter the float chamber passage directly, but must first reach the level of the top of the standpipe, and inasmuch as water, grit, etc. are heavier than gasoline, these foreign elements tend to remain on the bottom, so that only clean fuel enters the standpipe.

The strainer should be drained and the filter cleaned at frequent intervals to prevent any accumulation of water and dirt. It is not sufficient merely to drain the chamber for two reasons. First, any foreign matter which is inside the strainer will not be removed, and second, the screen may be sufficiently clogged to prevent proper passage of fuel and if such is the case, draining the chamber will not remedy the situation. It is especially important to clean the strainer before every flight that is likely to include any violent air maneuvers. Such maneuvers agitate the contents of the strainer chamber so that any accumulation inside the screen may be admitted into the standpipe and consequently to the carburetor proper where it is likely to cause trouble.

Cleaning the Strainer - There are many types of strainers, therefore it is impractical to give the exact procedure to follow in each case, however the following general rules are applicable to most types:

1. Make sure that the fuel supply to the carburetor is off.

2. Remove the strainer cover and the strainer.

3. Drain the strainer chamber. Note: If any water is discovered in the chamber an immediate investigation must be made to ascertain the cause.

4. Replace and safety the drain plug.

5. Inspect the filter to see if any particles of rust, fabric, rubber, or other foreign matter are present. Rust particles may indicate that the fuel tank is rusting (if it is made of terne plate or some similar material) or it may mean that fuel which is put into the tanks is not clean. Bits of fabric or rubber may be from some deteriorating hose connection.

6. The strainer screen should be cleaned by rinsing it in clean gasoline and cleaning with compressed air. If this does not dislodge all the accumulated dirt, the process should be repeated. Never attempt to clean the screen with a wire brush or any tool that may damage it. A stiff, short bristle brush, such as a toothbrush, may be used satisfactorily.

7. Replace the strainer carefully, making sure that it is inserted in the correct position.

8. Replace and safety the strainer chamber cover. Note: If a lead gasket is used, inspect both sides of it before replacing, as any particles of sand or grit that may be imbedded in the lead will often prevent it from forming a tight seal.

9. Turn the fuel on and test the cover and drain plug for any indications of leaks. If the fuel system is of the pressure type, the hand wobble pump should be operated until full pressure is indicated by the fuel pressure gage before the inspection is made.

Float Mechanisms - It is essential that the fuel within the carburetor discharge nozzle be kept at a constant level in order to insure a consistent fuel-air ratio. This level is most easily maintained by connecting the discharge nozzle directly to a constant level reservoir. Most carburetors employ the use of a float-valve mechanism to regulate the fuel admitted to this reservoir, or float chamber, as it is called. By referring to Fig. I the details of a typical float mechanism and the relationship between its various parts will be clearly seen. In this illustration the float is seen in the position it assumes when the fuel has reached the level indicated by the straight dotted line. It will be noticed that in this position the float arm, raised on one end by the buoyancy of the float, exerts a downward pressure on the needle valve at the other end. When the needle valve is in its down position, its tapered point is pressed firmly against the needle valve seat, preventing further fuel from entering the float chamber. As the fuel level in the float chamber is lowered the float descends, raising the needle valve and permitting additional fuel to flow into the chamber. With no fuel in the carburetor the float descends to the position shown by the dotted line, leaving the needle valve open. Actually, when a constant drain is being made on the fuel in the float chamber, the float does not alternately open and close the needle valve, but assumes an intermediate position whereby the needle valve opening is just sufficient to supply the required amount of fuel and keep the level constant.

The correct float level varies with different carburetors so that it is impossible to state just what the level should be; however, this information is usually printed on a metal tag attached to the carburetor bowl. The float level is given in fractions of an inch from the parting surface. The parting surface, or the joing between the upper and lower halves of the carburetor, is of course, above the float level, consequently the measurement must be made from this surface down to the level of the gasoline.

Measuring Float Level - To determine the float level when the carburetor is disassembled the lower half should be securely braced or fastened in a level position. It is important that the bowl be exactly level in both directions, as otherwise an accurate reading cannot be obtained. After the carburetor bowl is in position, fuel should be introduced into the float chamber through the fuel inlet passage. Some device should be arranged so that the same pressure is exerted on the fuel as would be done were the carburetor installed

on the engine. For example, if the airplane is equipped with a fuel pressure system and the gasoline is forced to the carburetor with a pressure of 3 lbs./sq.in., this pressure should also be used for introducing the gas when testing the float level. One of the simplest ways of making a satisfactory device for obtaining experimental pressure feed is to assemble a small air pressure tank, as shown in Fig. II. After it is attached to the carburetor the pressure in this tank is increased by means of the hand pump until the correct pressure is obtained, as indicated on the air pressure gage. Another method of obtaining the correct pressure is to connect a long vertical tube by a short piece of hose to the carburetor inlet. The gasoline is then poured into the vertical tube until a head corresponding to the correct pressure is obtained. For example, to produce a three-pound pressure, a head of 117" is required.

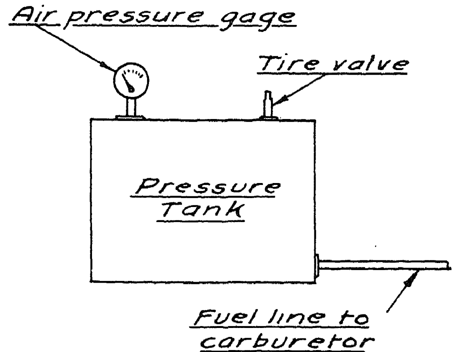


FIG. II

After making sure that the carburetor is in the level position and that the correct pressure is applied to the fuel, the fuel level may be checked by measuring the distance from the parting surface to the fuel. It should be remembered that this measurement should not be taken adjacent to the side walls or any other part of the bowl, as capillary attraction causes the fuel to rise slightly at these points. The correct method is to place a straight-edge across the parting surfaces and, using a steel scale, measure the distance from the straight-edge to the level of the fuel at some unobstructed point.

The fuel level can also be measured while the carburetor is assembled by means of a glass stand pipe. The general procedure in this case is similar to that described above. The stand pipe consists of a vertical glass tube of one-half inch diameter or over, which has been connected by a short length of rubber hose to the float chamber drain opening. The carburetor is levelled and gasoline under the correct pressure is admitted until the fuel in the float chamber has reached its maximum level. The fuel level will now be indicated by the level of the fuel in the glass tube. It is sometimes difficult to obtain a true measurement from the level of the fuel in the stand pipe to the parting surface of the carburetor. This may often be done by checking both measurements with a surface gage from a level surface plate below the carburetor.

If the level of the fuel in the float chamber is too high, there will be a correspondingly high level in the discharge nozzle. In

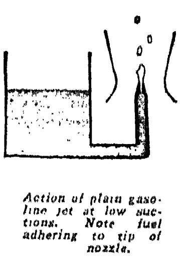
this event, when the engine is in operation, too much fuel will be drawn into the cylinder, resulting in a mixture that is too high in fuel content or, as it is generally termed, a rich mixture. Conversely, if the fuel level is too low a lean mixture will result, for more suction will be required to draw the fuel from the discharge nozzle. Either condition will affect the efficient or proper running of the engine and should be corrected by adjusting the float level. Note: The level reached by the fuel in the float chamber depends somewhat upon the specific gravity of the fuel used, being slightly higher as the fuel is lighter and also upon the pressure or fuel head at the carburetor inlet. Stromberg aircraft carburetors are set at the factory so that the float valves will operate properly and hold the level sufficiently close with fuels ranging between 55° and 76° Baume gravity, specific gravity .7[illegible] to .[illegible]. The running level is usually about 1/8" below the standing level and the vibration keeps the fuel splashing considerably above this level.

Adjusting the Float Level - If the level of the fuel in the float chamber varies more than 1/16" from that recommended by the manufacturer it should be changed accordingly. This is usually done by varying the thickness of shim washers underneath the needle valve seat assembly. If the needle valve moves downward to close the seat the fuel level may be raised by lowering the seat. If the needle valve moves upward to close the seat the float level may be raised by raising the seat. In either case the adjustment is made by removing some of the laminated shim washers between the needle valve seat assembly and its base. As various types of carburetors have various lengths of float arms it is impossible to state the exact relationship between the thickness of the shim and the increase or decrease of the float level. Normally, the addition of a 1/64" shim washer will decrease the float level approximately 5/64".

The following discussion of the theory, function, inspection and overhaul of the various parts of the carburetor applies more specifically to the Stromberg carburetors. It is reprinted from the Stromberg Carburetor Manual by the courtesy of Bendix Stromberg Carburetor Co.

BASIC PRINCIPLES OF STROMBERG AIRCRAFT CARBURETORS

"The Plain Jet and The Air Bleed - (Main Metering System) It is generally believed that a simple plain fuel jet in a carburetor air opening of fixed size tends to deliver a continuously richer mixture as the engine suction and air flow increase, but this is not accu-

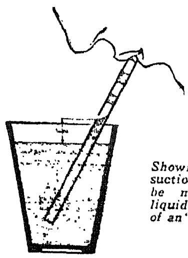


Action of plain gasoline jet at low suctions. Note fuel adhering to tip of nozzle.

Fig. I

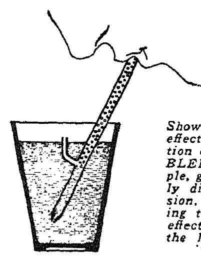
Showing how suction may lift liquid without drawing any of it away

Fig. II



Showing how the suction of Fig. 2 may be made to draw liquid, by the action of an "AIR BLEED."

Fig. III



Showing a more effective application of the "AIR BLEED" principle, giving a finely divided emulsion, and reducing the retarding effect of lifting the liquid above

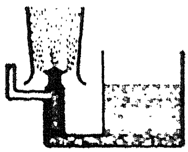
Fig. IV

rately true. Under the suctions of medium and high engine speeds, as carburetors are now built, a plain jet will give a fairly uniform mixture; but coming down to low speeds and suctions, the jet delivery falls off very markedly in relation to the air flow. This is due to the fact that some of the suction force is consumed in raising the fuel from the float level to the jet outlet (to avoid overflow with motor not running, the jet must necessarily stand a safe distance above the fuel level), and in overcoming the tendency of the fuel to adhere to the jet tip. At low suctions, the discharge from a plain jet is as shown in Fig. I with the fuel clinging to the metal of the jet and tearing off intermittently in large drops. The discharge from a plain fuel jet is, therefore, retarded by an almost constant force, which is insignificant at high suctions, but which perceptibly reduces the flow at low suctions.

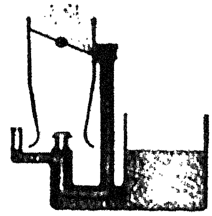
"The application of the 'Air Bleed' principle in overcoming this difficulty is shown in the accompanying illustrations. Fig. II shows a familiar instance of how suction may be great enough to lift a liquid above its level, without drawing any of it away. Now if a tiny air hole be pricked in the side of the straw above the liquid surface and the same suction applied as before, bubbles of air will enter the straw and the liquid will be drawn up in a continuous series of small slugs or drops, as shown in Fig. III.

"Such a construction is not quite suitable for a carburetor jet, as there is still a distance through which the liquid must be lifted from its level, before the air begins to pick it up; also the free opening of the straw at its bottom prevents very great suction being exerted on the air bleed hole or vent, just as too large an air opening in proportion to the straw size would reduce the suction available to lift the liquid. A modification to take care of these points is shown in Fig. IV, in which the air is taken in slightly below the liquid level and a restricting orifice placed at the bottom, with the result that a finely divided emulsion of air and liquid is formed in the tube.

"The construction just described, when incorporated into a carburetor jet, takes the form shown in Fig. V. Such a jet tends to give a substantially uniform mixture under steady speed throughout its range of operation. The mixture proportion can also be modified for high speed and low speed as desired by the proper selection of



A carburetor nozzle employing the "AIR BLEED" principle, the Stromberg Main Discharge Jet.



Showing combination of an idling passage beyond the throttle, with elements previously described. Note the location of the restrictions in the idling channel.

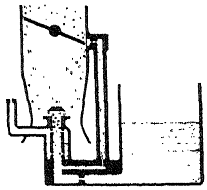
Fig. V

the dimensions of the air bleed and emulsion channels.

"The Venturi Tube - It is a fortunate and useful result of natural laws that both the air flow through an opening of fixed size and the fuel flow through an 'air bleed jet' system respond in substantially equal proportion to changes of suction (within the range of air velocities used in the carburetor). To maintain an approximately uniform mixture proportion throughout the power range of engine operation, it is only necessary that the 'air bleed jet' and metering air opening be exposed to the engine suction in the same degree, which condition is obtained by locating the fuel jet outlet in the center of a definitely formed air nozzle or venturi tube (sometimes called the 'choke'), as shown in Fig. V, both being on the atmospheric side of the throttle valve.

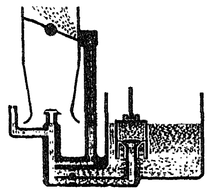
"The venturi tube has another use than this, however. As previously stated, full power output from the engine requires that the manifold suction or partial vacuum above the throttle be between .4 and .8 pound, at full engine speed, when the suction below the throttle valve is the maximum. From the standpoint of metering and spraying the fuel, it would be desirable to use a suction several times this. It has been found that both these requirements can be complied with by the use of the peculiarly shaped air passage of a venturi tube, consisting of a reduced or constricted central portion with a smooth round entrance and a gradually tapered outlet. With this it is possible to obtain, on a jet located in the central portion, several times the suction existing in the intake passage beyond the venturi tube, and thereby maintain a low manifold vacuum with a high fuel metering suction.

"As the venturi tube constitutes the limitation of air capacity of the carburetor, it is made in different sizes which may be selected according to the requirements of the engine to which the carburetor is fitted. The size is usually selected such that at normal full speed and load, there will be a mean air velocity (during the suction stroke) of 300 feet per second through the throat or narrowest part. This air velocity should correspond to a mean partial vacuum at the mouth of the carburetor, with throttle full open, of about 16 inches water during the suction stroke with the carburetor supplying four or more cylinders, 12 inches when supplying three cylinders and 4 inches when supplying one cylinder.



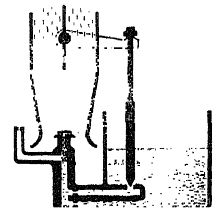
Accelerating well with main discharge jet and idling passage.

Fig. VII



Accelerating pump operated by throttle with main discharge jet and idling passage.

Fig. VIII



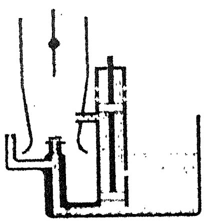
Needle valve economizer operated by throttle, with main discharge jet.

Fig. IX

"The Idling System - The structure of Fig. V does not entirely meet the requirements of carburetor service because at low engine speeds the air flow does not have sufficient force to carry the fuel from the jet to the throttle valve. As shown in Fig. VI a bypass or idling passage is provided to carry the fuel up to the throttle valve and intake manifold when the main jet suction is weak. This bypass system is practically independent of the main jet metering system and only controls the fuel metering at low engine speeds when the main jet suction is low. As this suction increases fuel will begin to deliver from the main system and the delivery from the idling system will decrease.

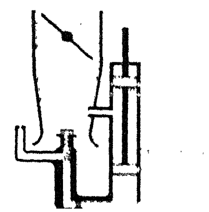
"The Accelerating System - It will be obvious that quick changes of engine speed and throttle position would involve rapid reversals to fuel flow through this idling system, tending toward temporary periods of lean mixture. It has been found that these may be avoided by the use of an 'Accelerating Well' (see Fig. VII), which is merely a downward extension or enlargement of the air bleed passage. The depression or suction in the central channel is always greater than in the outer 'Well' chamber, and any increase in suction on the main jet results in a lowering of the level in the well chamber. The volume of fuel thus displaced temporarily supplements the fuel delivered through the metering orifice, covering up any lag in either the idling tube or main jet passages, and gives a rich mixture when the throttle is opened quickly from low speeds. On engines with long manifold passages operating under cold weather conditions, greater quantities of fuel than that supplied by the accelerating well around the main discharge nozzle are required, and a pump operated by the throttle is used. This pump, as shown by Fig. VIII, is located in the float chamber. As the throttle is opened the sleeve is depressed, forcing fuel through the connecting passage, and out the main discharge jet. A restriction in the connecting passage limits the quantity of accelerating charge pumped.

"The Economizer System - As explained previously, it is desirable to have a lean mixture for maximum economy at part throttle or cruising speeds, and a much richer mixture for maximum power and the cooling effect on air-cooled engines, at full throttle. In order to obtain this change in mixture ratio as the throttle is opened various forms of economizer systems are used. These in their present form are in reality enrichening devices. The arrangement shown in Fig. IX consists of a needle valve, which is opened by the throttle



Piston type economizer operated by throttle with main discharge jet Full throttle.

Fig. X



Piston type economizer operated by throttle with main discharge jet Part throttle (cruising)

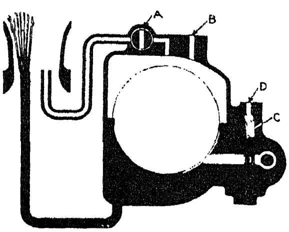
Fig. XI

at a predetermined throttle position, and permits a quantity of fuel, in addition to that furnished by the main metering system, to mix with the air in the carburetor. Fig. X shows a piston type economizer also operated by the throttle. The lower piston acts as a fuel valve, preventing any flow of fuel through the system at cruising speeds, while the upper piston acts as an air valve, and permits air to flow through the separate economizer discharge nozzle at part throttle. As the throttle is opened, the lower piston uncovers the fuel port, so that fuel is drawn through the system and out the discharge nozzle, and the upper piston cuts off the air bleed to the economizer nozzle, thus increasing the suction on the fuel jet. Fig. XI shows the position of the pistons of the same system at cruising speeds.

"Mixture Control - As the airplane ascends in altitude the atmosphere decreases in pressure, temperature and density. The weight of the air charge taken into the engine decreases with the decrease in air density, cutting down the power in about the same percentage. In addition, the mixture proportion delivered by the carburetor is affected, the mixture becoming richer at a rate inversely proportional to the square root of change in air density.

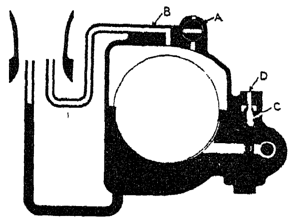
"In order to compensate for this change in mixture, a manually operated mixture control is provided on all Stromberg Aircraft Carburetors. The mixture supplied by a carburetor may be made leaner, by reducing the effective suction on the metering system, by restricting the flow of fuel through the metering system, or by admitting additional air into the induction system through an auxiliary air entrance. Each one of these methods has been used in Stromberg Aircraft Carburetors.

"Float Chamber Suction Control - The float chamber suction type of control, sometimes called Back Suction Control, operates to reduce the fuel flow by placing a certain proportion of the air passage suction upon the fuel in the float chamber, so that it opposes the suction existing in the main discharge jet. Figures XII to XIV show the general arrangement of this type of control. The simple carburetor illustrated has a venturi, a fuel nozzle, and a float chamber fuel supply with two openings at the top, one connected to the same suction as the fuel nozzle, and the other connected to a region of no suction. In Fig. XII a valve 'A' is shown in the suction opening. With this valve closed, there is the ordinary condi-



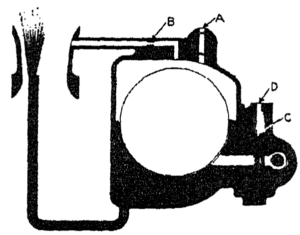
Mixture control valve in suction passage. Full rich position.

Fig. XII



Mixture control valve in passage to atmosphere. Full lean position.

Fig. XIII



Arrangement used in Stromberg Carburetors. Mixture control valve in passage to atmosphere. Restriction in suction passage. Full rich position.

Fig. XIV

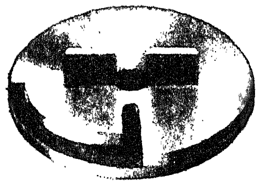
tion of carburetor action with suction on the jet, and no suction but simply atmospheric pressure on the float chamber. This condition exists when the mixture control is in the full rich position. If this valve is opened, some of the suction existing on the jet is imposed on the float chamber, which opposes the jet suction, and decreases the fuel flow.

"In Fig. XIII a valve 'A' is shown in the passage opening to the atmosphere. With the valve closed, as shown, no fuel would discharge because the suction would be the same on either side of the jet system. There would, of course, be suction above the fuel in the float chamber, which would tend to draw more fuel through the needle opening 'D', but provided the float were sufficiently large, the valve 'C' would hold shut, and maintain the level in the float chamber at the normal height. This corresponds to the extreme 'lean' condition that could be obtained with this type of control, in which there would be no fuel flowing. As this valve is opened, air is admitted to the float chamber, thus reducing the suction on one side of the jet system and fuel flow will start, due to the higher suction at the jet in the venturi. With the mixture control in the full rich position this valve is wide open.

"In actual construction the suction connection is taken from a location of lower suction, and a small restriction of fixed size placed in this passage, as shown in Fig. XIV. With this arrangement the valve 'A' may be completely closed without entirely stopping the flow of fuel. With the valve in intermediate positions, the pressure in the float chamber will not be equal to the full suction on the jet, nor will it be atmospheric pressure, but somewhere between, depending on the valve opening. With the valve 'A' in a fixed position the pressure in the float chamber will always be the same percentage of the suction at the discharge nozzle, regardless of how this suction may vary, so the action is uniform at all working speeds.

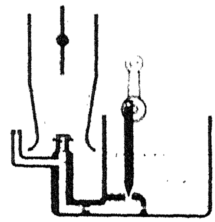
"In order to obtain a control that is not too sensitive to adjust, the closure of the valve must be rapid at first and then more gradual, and this is obtained by the use of a peculiarly shaped flat disk valve working upon an elongated slot, as shown by Fig. XV. This type of valve produces changes in the mixture ratio directly proportional to the valve movement.

"<u>Needle Valve Control</u> - The needle valve type of mixture con-



Altitude control disc valve and plate on which it seats. (Illustration approximately full size.)

Fig. XV



Needle valve type mixture control, with main discharge jet

Fig. XVI

trol is used to restrict the fuel passage to the main discharge jet, as shown by Fig. XVI. With the mixture control in the full rich position, the needle is in the raised position, and the fuel is accurately metered by the main restriction in the fuel passage. To lean out the mixture the needle is lowered into the needle valve seat, thus reducing the fuel supply to the main discharge jet. A small bypass hole, from the float chamber to the fuel passage, permits some fuel to flow, even though the needle valve is completely closed. The size of this bypass opening determines the range of control.

"'Automaticity' of Control - It will be noted that all of the control methods mentioned preserve the automaticity of the mixture range; that is, any given setting of the control reduces the suction or the fuel flow through the jet by the same percentage at all engine speeds. Since the delivery of the jet bears a constant ratio to the suction, any given setting of the control has a substantially uniform effect upon the mixture at all engine speeds, during which the main jet is in operation.

"Altitude Mixture Control Range - The range of the mixture control is usually designated in terms of altitude. This means that a carburetor having a correction range of 20,000 feet will give the same mixture ratio at this altitude, with the mixture control set at full lean, as it would give at sea level altitude with the control set full rich. If a metering jet setting is used which gives a mixture richer than necessary on the ground, with the idea of using the mixture control to correct for this condition, the remaining control availabl for altitude use will be less than if the ground level jet setting was correct with the control full rich.

"The float chamber suction type and the needle valve type of mixture controls have a correction range of approximately 25,000 ft. altitude. After the limit of mixture control correction has been reached the airplane can ascend 5,000 to 6,000 ft. higher before the mixture will become rich enough to cause the engine to lose power, and several thousand feet more before the engine operation becomes excessively rough.

"Location of Float Chamber Atmospheric Vents - The pressure of the propeller blast is often an appreciable percentage of the difference in pressures in the carburetor causing fuel flow, and it is very important that whatever pressure disturbance is caused by the

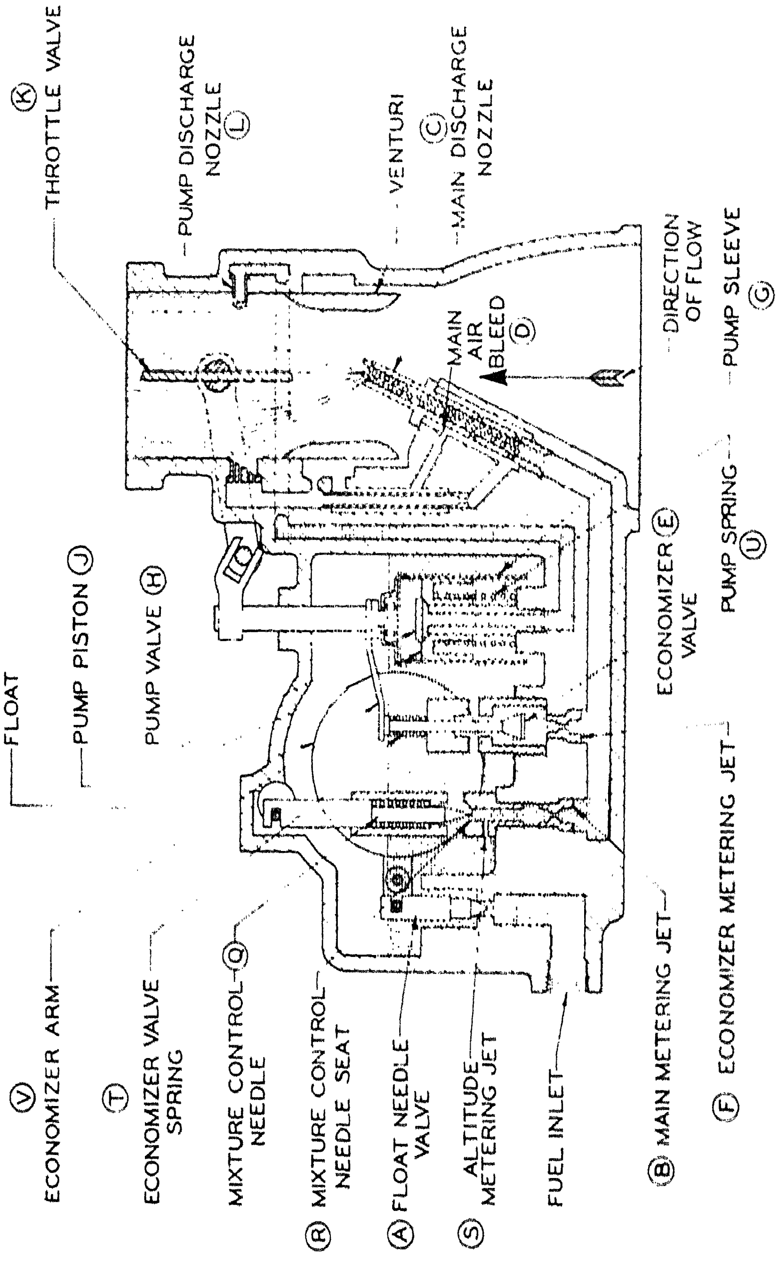
propeller blast should operate equally on both sides of the fuel metering jet, so that the fuel flow will be responsive only to the difference in pressures resulting from the flow of air through the carburetor. To insure this condition, the float vents, or mixture control openings, are brought to the air entrance of the carburetor. Any pressure disturbance resulting from the propeller blast or forward motion of the ship is thereby balanced equally on the float chamber and on the fuel jet. The air intake attached to the carburetor may cause turbulent or irregular flow of air into the carburetor so that different pressures will exist at various locations in the carburetor entrance. In order to obtain an average of these pressure valves in the float chamber the vent passage, on some carburetors, opens into an annular space formed by a groove cut in the outside of the venturi. This groove is connected to the air intake by means of four slots, which arrangement permits the use of air intakes of various designs without affecting the metering characteristics of the carburetor. Whatever slight depression may exist in the air entrance is transmitted to the float chamber and, for this reason, a manometer connected to the float chamber during dynamometer test may show some depression with either type of mixture control in the full rich position."

It is impractical and unnecessary to attempt to explain the functioning of each model of carburetor. It is suggested that the carburetor manufacturer's instruction manual pertaining to the carburetor in question be secured and studied. The following discussion of the NA-R4B model Stromberg carburetor will serve to illustrate how the subject is covered by the individual instruction books, and is reprinted through the courtesy of the Bendix Stromberg Carburetor Co. and Ranger Engineering Corporation.

FUNCTIONING OF STROMBERG NA-R4B AIRCRAFT CARBURETOR

"Main System - This carburetor operates on the same basic principles of other Stromberg models. Referring to Fig. I, it will be noted that fuel enters the carburetor from the fuel inlet, passes through float needle valve (A), then passes through the mixture control seat (R), and through the main metering jet (B), mixes with air from the main air bleed (D) in the main discharge nozzle (C) to form an emulsion which is discharged into the venturi. The emulsion then mixes with the air flowing through the carburetor and enters the engine for combustion. The air for the main air bleed (D) is taken from a space behind the venturi which is connected to the air intake of the carburetor. The main system is used for all engine speeds except idling.

"Economizer System - To provide a richer mixture at wide open throttle for maximum engine power, an additional jet is opened. This is the economizer metering jet (F), and the flow of fuel through this jet is regulated by the economizer valve (E). This in turn is operated by the economizer arm (V) connected to the pump stem which is actuated by a lever on the throttle shaft. As the throttle valve is closed, the economizer valve spring (T) closes the economizer valve (E), so at the cruising position of the throttle valve (K), the economizer valve (E) completely shuts off the flow of fuel through the economizer metering jet.



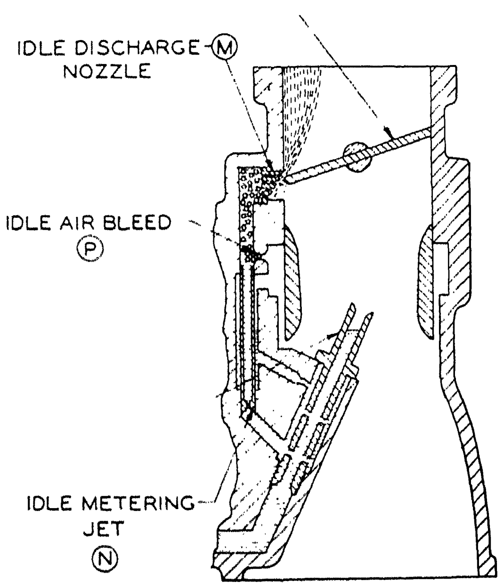
FULL THROTTLE

FIGURE I

"Mixture Control - It is a well known fact that the mixture will become richer as the density of air decreases, therefore in order to compensate for this enrichment when flying at altitudes, a mixture control needle has been provided which is operated independently of the throttle. As this needle (Q) is moved down into its seat (R) by the eccentric pin on the mixture control shaft, the flow of fuel may be lessened to give the required mixture. An altitude metering jet hole (S) is incorporated below the mixture control seat to prevent the fuel being shut off completely.

"Accelerating Pump - In order that the engine will accelerate quickly and smoothly, a pump is utilized to provide an additional charge of fuel as the throttle is opened. A pump sleeve (G) moves down as the throttle opens, and the force of the fuel inside the sleeve overcomes the force of pump spring (U), allowing the pump piston (J) to move down, opening holes in the pump valve (H). The fuel then starts to flow down through the pump valve and through appropriate passages to the pump discharge nozzle (L) where it is discharged into the carburetor barrel. The spring (U) gradually forces the piston (J) up, discharging the remainder of the fuel until it seats on the valve (H), shutting off the flow of fuel from the pump. As the throttle valve is closed, the sleeve is raised and the chamber within the sleeve is refilled with fuel, which flows around the outside of the piston from the float chamber.

"Idle System - When the engine is idling, the throttle valve is closed or nearly closed, so the flow of air through the venturi is not great enough to cause sufficient fuel to flow through the main discharge nozzle to give satisfactory engine operation. A separate idle system has, therefore, been incorporated to give the necessary fuel flow at low engine speeds. Referring to Fig. II it will be noted that fuel from the float chamber first passes through the main metering jet to the main discharge nozzle, flows through side holes in the main discharge nozzle and through the idle metering jet (N), then mixes with the air from the idle air bleed (P) to form an emulsion which is then discharged into the carburetor barrel through the idle discharge nozzle (M). As the throttle valve is opened, the suction at the idle discharge nozzle (M) decreases and the suction at the main discharge nozzle increases so that the fuel ceases to flow through the idle system and then flows through the main system.



IDLING

FIGURE 2

INSPECTION AND OVERHAUL

"Disassembly - The carburetor should be disassembled for cleaning and inspection each time the engine is given a general overhaul, when there has been an accident which might have damaged the carburetor, or when its action is known to be unsatisfactory.

"In disassembling, the halves should be separated and sufficient parts removed to permit a very thorough cleaning and inspection of all parts and passages. In general this will include the removal of the float mechanism, float needle valve seat, strainer, main discharge nozzle assembly, metering jets, economizer, accelerating pump, mixture control valve and such passage plugs as are required to clean the passages.

"Tapping the brass plugs lightly with a soft wood or rawhide mallet will aid greatly in their removal from the aluminum body. If the threads stick, apply oil and work the plug in and out as is sometimes done in a tapping operation. This will allow their removal without tearing the threads in the aluminum.

"Wash all parts and the aluminum castings with gasoline, and clean all passages by blowing through them with an air hose.

"Inspection - The parts removed should all be inspected carefully for wear or irregularities of any kind. Note the condition of the float needle valve and needle valve seat. If the needle is grooved or the sides of the needle valve or needle valve guide are worn excessively, both needle valve and seat should be replaced with new parts. See that the adjustable idle discharge nozzles are clean and that they can be freely adjusted. Check the fit of the throttle valves in the barrel and the fit of the throttle shaft in its bushings. On the double or triple-barrel models see that all of the throttles close tightly with the throttle stop unscrewed. An adjustment is provided, for synchronizing the throttles on double-barrel models having parallel throttle shafts connected with gear sectors. One of the gear sectors is not pinned to the shaft but is clamped directly to it by means of a bolt and nut. Loosening this nut will allow the gear sector to be turned on the shaft and an adjustment secured. On later models of this type the gear sector, which is not pinned, is fitted over an eccentric split bushing. This eccentric bushing may be rotated to eliminate excess backlash between the gear sectors. With this type of adjustment the gears should be set with practically no backlash when the throttles are closed. The backlash which will then exist at wide open throttle has no effect on the operation. Examine all passages to see that they are clean.

"Assembly - Reassemble the parts in the lower half or main body of the carburetor, using new parts where necessary. It is very important that all gaskets be in good condition and be properly placed.

"Brass plugs screwed into aluminum have a tendency to stick after a long period of service, but this trouble can be obviated by the application of a thin coating of a mixture of powdered graphite and castor oil to these threads.

"The needle valve and seat should be checked for leakage by

holding the needle valve with the point up and the seat in place, and filling the small space above the needle with gasoline. If any leakage is evident the needle valve should be lapped in with crocus powder. If the leakage cannot be stopped in this way a new needle and seat should be used.

"After assembling the lower half of the carburetor move the float up and down to see that it works free, and inspect it to see that it does not strike the sides of the float chamber. Check the float level by holding the lower half in a level position either on the bench or in a vise and connecting the fuel inlet to a fuel supply tank. Measure the distance from the level in the float chamber to the parting surface. This measurement should check with that given in the detail instructions on the model being tested. In case this information is not available the level should be set 1/8" to 3/16" below the bottom of the main discharge nozzle holes.

"The fuel used and the height of the fuel supply tank above the carburetor fuel inlet should correspond to the conditions actually encountered in service. If the carburetor is used on an airplane having a gravity fuel system the float level should be set with a fuel head equal to the average height of the fuel in the tanks of the airplane above the carburetor inlet. If used with a pressure fuel system a pressure of 3 pounds per square inch, or 117" of fuel at .710 specific gravity, should be used. In case the level is not correct, adjustment should be made by changing the thickness of the gaskets under the float needle valve seat. In general, a change of 1/64" in gasket thickness will cause a change of 5/64" in the level. In order to lower the level it is necessary to reduce the gasket thickness on some carburetors and increase it on others, depending on the location of the needle valve above or below the float bracket and on the location of the pivot between the float and needle valve or at one end of the float bracket. Whether to add or remove gaskets is easily determined, however, by an examination of the float mechanism construction.

"The setting in the carburetor should correspond to the setting shown on the aluminum tag riveted to the casting unless there is a definitely known reason why it should be otherwise. The individual instruction sheets, usually supplied in the engine instruction book, should be consulted for detailed information concerning each individual model.

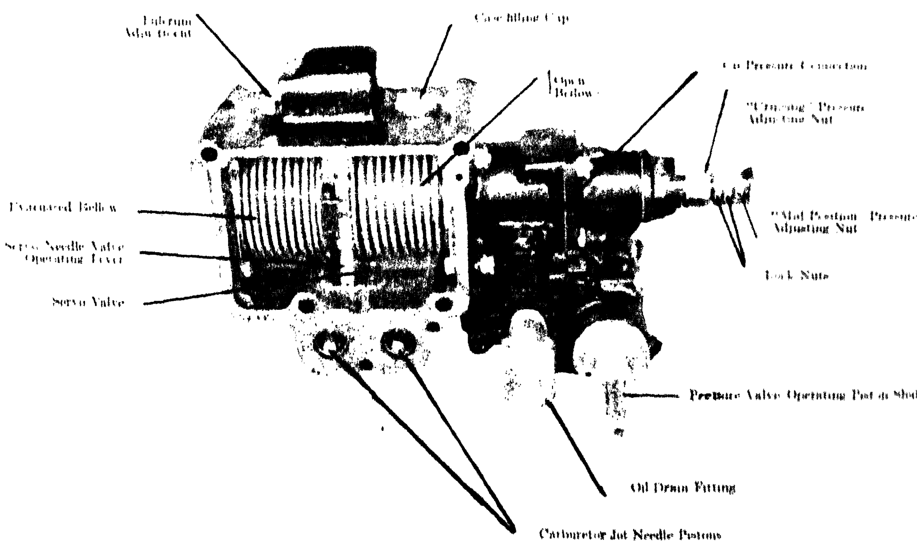
"Assemble the main and throttle valve bodies and safety wire all screws, plugs, etc."

Automatic Mixture Control - As has been previously mentioned, changes in altitude affect the carburetor mixture to such an extent that proper engine functioning cannot be obtained without adjusting the carburetor to allow for these changes. Most carburetors are equipped with some device for making suitable altitude compensations yet these mechanisms are not entirely satisfactory, for it takes a pilot an appreciable length of time to adjust manual controls to obtain powerful yet economical engine performance at various altitudes. It is particularly important that the pilot be relieved of

this duty on flights where the altitude is being changed constantly, such as in military maneuvers. Obviously, the necessity for making carburetor setting adjustments would be eliminated if the air delivered to the carburetor intake horn remained at a constant pressure, for it is the varying pressure at this point that results in different fuel-air ratios. It is possible, through the use of an external supercharger, to maintain a constant air intake pressure, thereby eliminating the use of a mixture control. While this method of altitude compensation is effective, it is not in general use since it involves the use of an exhaust driven supercharger, with consequent increase in weight and possibilities of mechanical failure. Another, and more popular, method of achieving the same result is by means of an automatic mixture control unit, such as the one described below.

Briefly, the function of the automatic mixture control unit is to regulate the fuel-air mixture so that it is delivered to the engine in a constant ratio, irrespective of the altitude or the density of the atmosphere. Essentially this function is performed by maintaining a constant pressure at the carburetor air intake horn. Such constant pressure is made possible by the installation of pressure control valves in the carburetor air intake. These valves and the air intake are arranged to work effectively within a predetermined range, usually from sea level to 12,000 ft. They are so designed that when the valves are wide open at the maximum altitude there is as much pressure created in the air intake as there is when the valves are closed at sea level.

The pressure control valves are actuated by an operating piston which in turn is controlled by oil pressure as follows: An air pressure tube is located in the carburetor intake and is connected to the open bellows shown in Fig. I. As the air pressure in the intake



COURTESY OF PRATT+WHITNEY *Automatic Mixture Control Unit* Fig. I

begins to drop, some pressure is removed from the open bellows which allows the evacuated bellows to expand. When the evacuated bellows expands, a Servo valve is moved allowing oil pressure (from the engine oil pressure system) to act on one side of the control valve operating piston. The oil pressure moves the piston inward, which opens the pressure control valves further and this in turn admits more air into the intake, hence the pressure is increased. When the pressure in the air intake starts to rise, the procedure is reversed and the pressure control valves close slightly, decreasing the air admitted, and likewise the pressure. In actual operation, this process does not continually alternate as described here, but assumes a state of equilibrium which allows for slight pressure changes. The sensitivity of this control can be regulated by the fulcrum adjustment, shown in Fig. I. By the method outlined the pressure variation is effectively controlled within definite limits, but it will be noted that this is accomplished by reducing the available sea level pressure. This means that the engine cannot develop as much power as it could without the control unit until it reaches the maximum altitude above which the unit is not effective.

It is often desirable to utilize more engine power than is available when using an air intake pressure equivalent to 12,000 ft. altitude. In order to do this the mixture control unit is provided with an adjustment, controlled from the cockpit, which permits a higher intake pressure. This new position allows the pressure to be maintained at some previously fixed constant. For example, if the second position of the control unit is adjusted to a pressure equivalent to 6,000 ft. altitude density, the pressure control valves in the air intake are actuated so that this pressure is maintained from sea level to 6,000 ft. As the engine is then operating at a higher intake air pressure, more fuel will be needed. To provide the additional fuel required, the automatic mixture control mechanism opens an auxiliary jet in the carburetor as soon as it is turned to this new position. When the control is so adjusted, it is said to be in its mid-position, or the high power cruising position. In either the cruising position or the mid-position the throttle may be left wide open and the engine will not exceed its maximum cruising r.p.m. until after the critical altitude has been reached.

To take care of emergency, a third position of the automatic mixture control unit is provided. When the unit is shifted to this emergency position the pressure control valves are held wide open at all times and also additional jets in the carburetor are opened to assure sufficient fuel supply. In this position, the carburetor is practically the same as though it were not equipped with the control unit.

The automatic mixture control does not interfere with the manual control of the throttle or carburetor mixture, but as long as it is functioning properly within its limits there is no need to use either of these manual controls except for landing. If, for any reason, the unit fails to function due to lack of oil pressure, mechanical failure, etc. it is automatically placed in the emergency position and the engine may be controlled manually.

CHANDLER-GROVES CARBURETOR

The Chandler-Groves carburetor differs radically from conventional carburetors in that it has no jets, fixed venturi or float chamber. Its important feature is a diaphragm fuel control and it is so designed that it offers automatic altitude adjustment, reduction of ice formation hazard and automatic priming, as well as power compensation and a positive acceleration pump. Fig. I shows an assembled Chandler-Groves down-draft carburetor, viewed from the top, or air scoop end. In this view the throttle arm will be seen at the lower right hand corner. The diaphragm sections are at the left side. The cross member seen through the air intake opening is the metering needle housing.

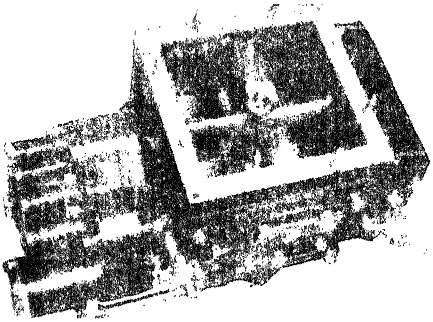


Fig. I

Fig. II

Fig. II shows a detailed view of the main body of the carburetor. The metering needle housing is clearly shown supporting the streamlined paddle-shaped main discharge nozzle. The quadrant-shaped sections shown on either side of the discharge nozzle are the two throttles. They are shown in a three-quarters open position. When the throttle is closed these sections rotate inward to reduce the opening at the discharge nozzle. Movement of the throttle arm also controls, through a cam-lever mechanism, the movement of the main metering needle.

The three diaphragm sections are shown in Fig. III. The power compensator section is shown at the left. The main fuel section, which has two diaphragms, is centrally located while the accelerating pump section is shown on the right. It will be noticed that this carburetor is comprised of many sections, thereby avoiding large and complicated castings. This is a noteworthy feature, as it simplifies the maintenance and replacement of parts. The diaphragms are made of soft pliable leather to which are attached thin metal discs. The leather not only forms a good seal between the various sec-

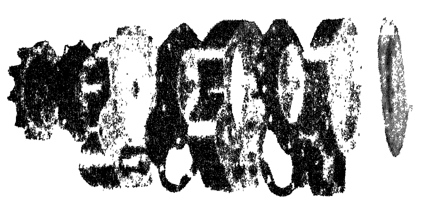


Fig. III

tions but its flexibility permits smooth, even diaphragm movement.

Figures I, II, and III are reproduced through the courtesy of the Chandler Groves Company, who originally manufactured this carburetor for military use only. However, it is now available commercially and is used on many of the higher powered engines. A schematic drawing of this carburetor is shown in Fig. IV in order to simplify the explanation of its functions.

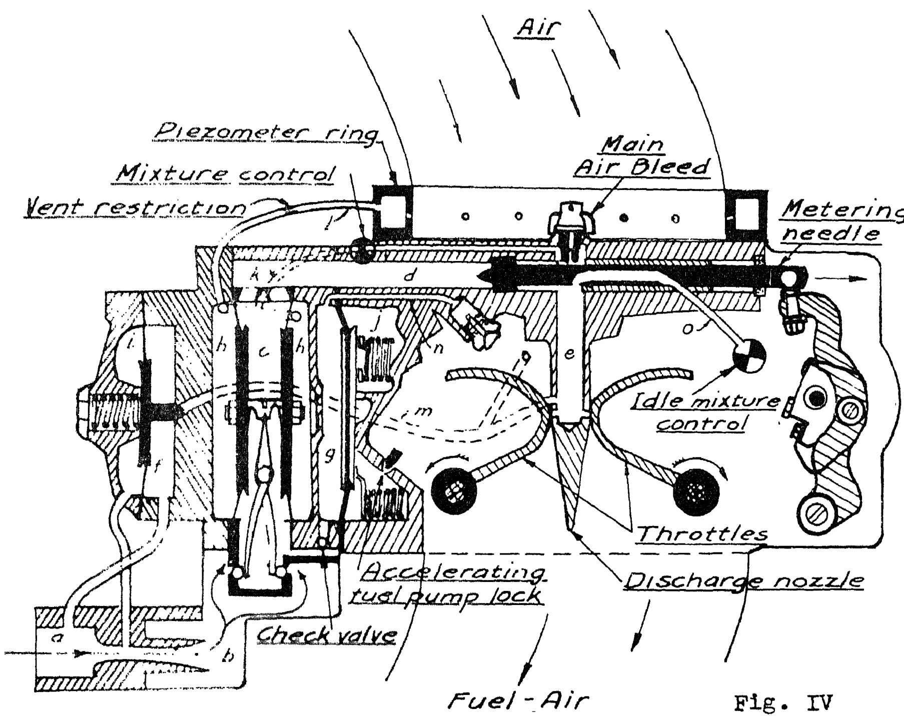


Fig. IV

Main Fuel Feed - Fuel, under a pressure of six to seven pounds, enters the carburetor through the fuel inlet opening, a. From here the fuel flows through the venturi passage into the chamber, b, and through the ball check passages to the main fuel chamber, c. After the fuel reaches a certain level in this chamber it exerts sufficient pressure to force the main diaphragms outward. As the diaphragms move outward the two lever arm attachments are actuated so as to close the ball check passages between the chambers b and c, thus preventing further admission of fuel. When the engine is running, the air rushing through the air scoop and past the main air bleed creates a suction which is transferred through the main fuel passage channel d back to the chamber c. Note: This can happen only when the metering needle is open, as would be the case when the engine is running. The opening from the main fuel chamber is at the top so that the fuel passes directly into the main fuel channel d.

Thus, when the engine is running, the entire fuel chamber is filled, making it possible for the carburetor to function normally when the ship is in inverted flight. By eliminating all air space in the fuel chamber there is no possibility of an interrupted flow of fuel during violent maneuvers. The fuel channel, d, is connected to the main discharge nozzle, e, so that the fuel that is drawn into the main channel flows into the nozzle e, from which it is discharged into the passing air stream, through small openings in the sides of the paddle-shaped nozzle. There is considerable suction at the point of discharge, due to the shape of the throttles and the discharge nozzle, which combine to form a variable venturi opening.

Ice Formation - The possibility of ice formation is practically eliminated by the simple expedient of introducing the fuel into the air at a point below, or on the induction side of, the throttle. Thus, the fuel-air mixture is introduced into a chamber which is practically free from all obstructions such as butterfly valves, etc. upon which ice could form. It is not necessary to use a carburetor air preheater with this installation, thereby eliminating 30 lbs. or more of weight.

Mixture Control - The air chambers, h, are connected to the piezometer ring and also to the main air bleed in such a manner that a percentage of the same suction that exists at the metering needle is applied on these chambers. As part of the suction is applied on chambers h, it is more difficult for the fuel to be drawn from chamber c and, in addition, the available suction at the main air bleed is also reduced, consequently there is less suction exerted on the main fuel chamber. The above conditions combine to reduce the amount of fuel delivered to the main discharge nozzle e, thereby resulting in a leaner mixture. This entire action may be summed up by saying that the suction at the main air bleed draws the fuel to the discharge nozzle, but the free flow of fuel is regulated by utilizing a percentage of the same suction to retard the flow of fuel. In this manner a constant fuel-air ratio is maintained not only throughout the entire engine operating range from idling to high speed but also in the varying air conditions found at different altitudes.

Manual Mixture Control - In order to provide for more exact altitude compensation and to permit leaning of the mixture for more economical cruising, a manual mixture control is installed in the air passage between the main air bleed and the chambers h. This consists of a restriction valve which opens and closes the air passage. In the full rich position the air passage is entirely closed, allowing the entire suction at the main air bleed to be utilized for drawing the gas from the fuel chamber. The amount of suction is further controlled by a diaphragm vent restriction placed in the air passage between the piezometer ring and the chambers h. This restriction bleeds off a portion of the suction so that when the manual mixture control is in the full lean position the resulting fuel-air ratio will not be less than the allowable minimum. This one manual mixture control regulates the mixture over the entire range of engine operation. A further function of the mixture control is to shut off the flow of fuel, thus preventing the engine from afterfiring when it is stopped. This is accomplished by moving the mixture control to its full travel beyond the cruising lean stop, which

exposes the outside of the diaphragms to practically the same suction as exists at the fuel metering restriction and at the same time locks the accelerating pump. With the suction thus balanced, the diaphragms act to close the fuel inlet valves and completely cut off the fuel supply.

Power Compensator - A power compensator is provided to increase the richness of the mixture which is necessary when the engine is approaching its maximum power output. This unit is located at the left hand side of the carburetor illustration, Fig. IV. As fuel enters the carburetor chamber a, the compensator fuel chamber f is filled. Under normal operating conditions the fuel does not leave this chamber, as the exit is closed by the spring loaded diaphragm needle valve. As the fuel flow through the venturi is increased, a suction is produced on the spring side of the compensator diaphragm. When this suction has been increased sufficiently, the diaphragm operates against the spring, opening the needle valve passage and allowing the fuel in the compensator chamber f to pass directly into the main discharge nozzle e. As long as the suction on the compensator diaphragm is great enough to hold the needle valve off its seat the fuel continues to flow to the discharge nozzle, thereby enriching the mixture.

The power compensator is calibrated to provide the proper amount of fuel with six to seven pounds of pressure at the carburetor inlet. It is important that this pressure be maintained, especially when operating the engine at or near its maximum output. If the pressure is allowed to drop below this point the compensator will not work efficiently, consequently the engine will not receive a sufficiently rich mixture. As the compensator works only at high power outputs the mixture is not affected at any other time by changes in fuel pressure.

Accelerating Pump - To insure rapid and positive acceleration of the engine when the throttles are opened quickly, the Chandler Groves carburetor is provided with a vacuum operated diaphragm type accelerating pump. This pump is located between the main fuel chamber and the body of the carburetor. Fuel enters the pump chamber g through the one way passage located between chambers b and g. The accelerating pump chamber is divided into two sections by a spring loaded diaphragm. The springs are on the air chamber side of the diaphragm and tend to apply pressure on the fuel. This side of the chamber is open to the vacuum that exists below the carburetor when the throttles are closed and the engine is running. This pulls the diaphragm against the springs and allows a greater quantity of fuel to enter the chamber g. When the vacuum is broken by suddenly opening the throttles the springs force the diaphragm to exert a pressure on the fuel in chamber g, forcing it through a drilled passage where it is discharged at the outlet spray nozzle. This provides sufficient additional gas to insure positive acceleration.

When the engine is stopped, a cam mechanism operated by the mixture control handle seals the vacuum on the spring side of the diaphragm. If the seals are in good shape this vacuum will remain in the chamber for a considerable length of time. Upon starting the engine, the mixture control is opened quickly, forcing fuel through

the spray nozzle into the induction system to serve as a priming charge.

Idling Adjustment - To obtain idling adjustment, an additional air bleed is used in the form of an adjustable valve. This valve operates only when the throttles are nearly closed since the air passage is in the center of the metering needle and is shut off as soon as the needle is moved out of its seat about 1/16". The idling adjustment is not effective for engine speeds above approximately 1,000 r.p.m. When the idling adjustment is fully open, air is allowed to enter the discharge nozzle, thereby leaning the mixture. As the idling air bleed passage is closed, less air is admitted, resulting in a richer mixture.

INDUCTION SYSTEMS

Broadly speaking, the induction system includes all of the devices and accessories which are used to supply fuel to the engine and which are affected by the suction produced by the downward stroke of the pistons. This includes such items as the air scoop, the carburetor air pre-heater, the carburetor, the hot spot, the manifolds, the diffuser and the supercharger. However, only the manifolds, diffuser and supercharger will be discussed here, as the other items have been described previously.

That portion of the induction system that is between the carburetor and the engine cylinders may be divided into three types, the manifold, the diffuser and the supercharger induction.

MANIFOLD SYSTEM

The simplest type of induction system is the plain manifold type. In this, the carburetor fuel mixture is carried directly to the cylinders through a series of pipes or tubes called manifolds, or induction pipes. The manifold system is used on practically all aircraft engines under 200 h.p. as it is inexpensive, light and practically trouble-free, and there are no moving parts involved.

DIFFUSER INDUCTION

Several of the medium sized engines, such as the Lycoming, Jacobs and others, use a diffuser induction system. The purpose of this system is to vaporize more thoroughly the carburetor charge and to assure equal distribution of the mixture to the various cylinders.

The diffuser acts on the same principle as the supercharger. The fuel charge is drawn directly into the crankcase, where it is subjected to the influence of a low speed impeller. The rotating impeller not only serves to vaporize the charge more thoroughly, but directs it in equal proportions to the diffuser outlets, thereby assuring an equal charge to each cylinder.

SUPERCHARGERS

Superchargers are used in induction systems to more thoroughly vaporize the fuel charge, to assure equal distribution to the cylinders and, in addition, to deliver the charge to the cylinders under a positive pressure. The latter item is what makes it possible for the supercharger to increase the normal rated h.p. of an engine at sea level, maintain engine power at altitude and to provide increased power at sea level for emergency. There are two types of superchargers, the internal and the external. The former, which is the more popular, will be discussed first.

Construction of Internal Superchargers - Many of the modern aircraft engines of over 200 h.p. and the majority of those of over 400 h.p. are equipped with internal type superchargers. These superchargers are simply centrifugal compressors which are driven through a series of gears by the engine crankshaft. One section of the crankcase is designed to form the supercharger housing. By thus incorporating the housing in the crankcase, considerable weight is saved over the external type. The high speed blower or impeller, which is the part that requires such careful engineering design and construction, is usually furnished by the General Electric Company, who have had many years' experience with this type of construction.

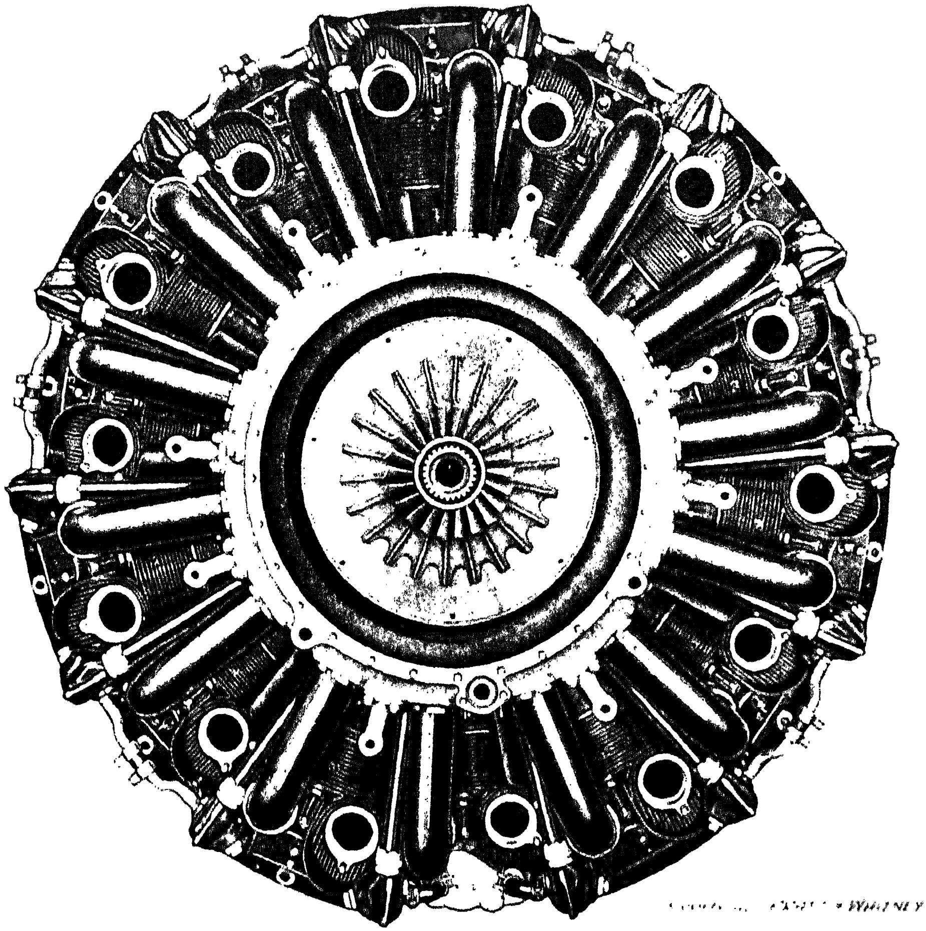


Fig. I

Introduction of the Fuel Charge and Impeller Action - Fig. I shows a rear view of a 14 cylinder Pratt & Whitney engine with the diffuser section removed so that the impeller may be seen. Fig. II shows the diffuser section. The carburetor mixture is drawn into the supercharger through the indirect opening in the central part of the diffuser section. Note: The opening shown in the center of the diffuser section forms a bearing surface for the impeller and also permits the stub shaft, which drives the accessories, to telescope into the crankshaft. It will be noticed that the incoming air charge enters the central portion of the impeller and also that the impeller vanes at this point are inclined or curved in the direction of rotation. This is so the impeller may pick up the charge with less shock, which not only increases the smoothness of operation but decreases the power necessary to run the impeller. Needless to say, considerable research and engineering skill was required to design

the impeller vanes in such a manner that the incoming air could be admitted to the impeller and gently directed along the vanes to the outer edge, or impeller exit as it is called, without setting up any conflicting turbulence.

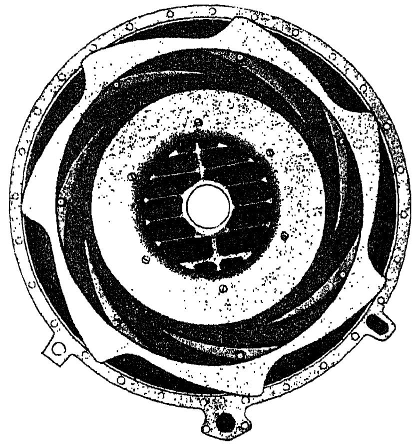


Fig. II

Impeller Speed - The impeller speed is always designated by the ratio between its rotation and that of the crankshaft. In order to produce the desired supercharging effects, the impeller must rotate at high speeds, ranging from 6:1 to 12:1. Some engine manufacturers use impellers of comparatively large diameter, thus making it possible to produce the same degree of supercharging with a lower impeller rotational speed. The skill and care with which an impeller must be made is forcefully illustrated by the fact that when the impeller is turning at top speed the tips of the blades are traveling from 500 to 1500 ft. per second, depending upon the gear ratio. For the sake of comparison, it will be remembered that sound travels only 1080 ft. per second.

Impeller Drive - The impeller is driven by the crankshaft through a series of induction gears. The gear arrangement varies with engines of different makes, but all which operate the impeller at high speed include some type of friction clutch arrangement. Such a clutch is necessary to reduce excessive strains that are imposed on the gear train during rapid acceleration and deceleration. For example, if an engine using an impeller with a ratio of 10:1 were rapidly accelerated from 1,000 r.p.m. to 2,000 r.p.m., the impeller would have to accelerate from 10,000 r.p.m. to 20,000 r.p.m. in the same length of time. Such acceleration would not only require considerable engine power, but destruction of some part of the mechanism would be likely to occur. To avoid these difficulties, a friction clutch is employed. This clutch is provided with a spring friction bearing between the drive shaft and the drive gear; thus, when an undue strain is exerted on the mechanism a certain amount of slipping occurs which allows the impeller to reach its proper speed without violent torsional strains.

Diffuser Action - The distributor vanes, or diffuser vanes, are clearly illustrated near the outside circumference of the diffuser section shown in Fig. II. These vanes are designed scientifically to receive the high velocity charge as it leaves the impeller vane exits. The diffuser vanes serve not only to insure even distribution of the fuel by directing it to all cylinder induction pipes evenly, but also to decrease the velocity of the air with the least friction

possible. By decreasing the velocity of the air without decreasing the amount of air, the pressure is raised, thus the charged air is delivered to the cylinders under a positive pressure. It is obvious that, such being the case, each cylinder receives a greater charge than would be possible by the suction of the piston alone. Naturally by increasing the amount of charge the power delivered to the crankshaft is also increased.

The vaporization of the fuel charge is also improved since the small drops of fuel in the air are broken up when subjected to such high velocity. Furthermore, as the fuel charge is compressed, the temperature is raised, which also improves vaporization.

Thus the supercharger delivers more fuel to the cylinders, and this fuel is in a more vaporized and hence a more volatile state than is the case when no supercharger is used.

Two Speed Superchargers - As one of the main functions of the supercharger is to supply sufficient fuel charge to the cylinders to maintain maximum power at altitude, it is obvious that the supercharger is capable of supplying too large a charge at sea level. If a supercharged engine is allowed to run at maximum power output at sea level, the engine speed and heat generated will be so great that engine damage will result. To avoid the possibility of this occurring accidentally, supercharged engines are provided with a throttle stop so that the engine cannot be run at its maximum without releasing the stop and moving the throttle handle further forward. Normally this is not to be done until the ship has reached a predetermined altitude, usually 5,000 ft.

From the foregoing, it is evident that a supercharger geared for high altitude is more effective than necessary at low altitude. Likewise, by reducing the rotational speed of the impeller the same supercharger is sufficiently effective at lower altitudes. Taking advantage of this fact, some engine manufacturers use a two-speed supercharger. The advantage of this arrangement is obvious. The low speed permits sufficient supercharging to allow the engine to develop its normal rated h.p. for take off and low altitude work. At the same time the impeller speed is lessened, thereby decreasing the power necessary to turn the impeller, and also reducing the fatigue strains which are a natural result of continued high speed.

The two speed supercharger is controlled from the cockpit and is shifted from low speed to high speed somewhere between 10,000 and 15,000 ft. altitude, or when increased supercharging is needed as indicated by the manifold pressure gage.

External Superchargers - External superchargers are used for two purposes. The type that is installed for operation from sea level to a normal high altitude of approximately 15,000 to 20,000 ft., is designed to keep a constant sea level pressure at the carburetor air intake horn. This enables the engine to develop its normal rated h. p. throughout the altitude range and eliminates the necessity for carburetor altitude mixture control.

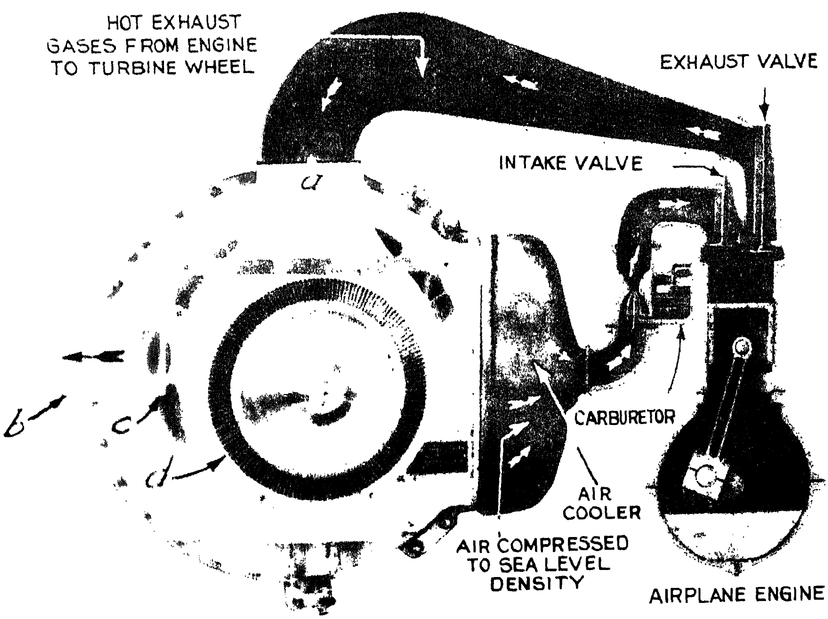
The other type, which is used for high altitude flying, is de-

signed so that it becomes effective only after the internal supercharger has reached its critical altitude, which is ordinarily about 20,000 ft. The function of this supercharger is to maintain a carburetor air intake pressure equivalent to the maximum pressure required by the internal supercharger. By so doing, the engine is permitted to develop its normal rated h.p. up to altitudes as high as 30,000 to 35,000 ft.

The exhaust driven turbo supercharger designed and built by the General Electric Co. and illustrated in Fig. III, has been used successfully as a second stage supercharger to maintain sufficient carburetor air intake pressure at altitudes above the effective range of internal superchargers.

The turbo supercharger is, of course, made in various sizes so that it can be made adaptable to individual engine requirements but the average unit is approximately 17" in diameter, 14" long and weighs about 130 lbs., excluding the inter-cooler. Where possible, it is bolted directly on the engine in such a manner that it will be centrally located between the exhaust outlet and the carburetor intake.

In operation the exhaust gases from the engine enter the supercharger unit at the top of the nozzle box, a. As long as increased supercharging is not needed the turbo unit remains inoperative and the exhaust gases are allowed to pass out through the waste gate, b, (indicated by black arrows). When the carburetor air intake pressure



TURBO SUPERCHARGER
Fig. III

Courtesy of General Electric Co.

begins to drop, due to increased altitude, the waste gate valve, c, begins to close so that more of the exhaust gas which is in the nozzle box is directed into the nozzle. The nozzle is so constructed that the exhaust gas which passes through is directed at the outer circumference of the turbine wheel which supports the small vanes or buckets, d. When sufficient exhaust gas is directed through the nozzle a rotary motion is imparted to the turbine and, as the centrifugal blower is mounted on the same shaft, it also begins to turn. Obviously, therefore, the position of the exhaust waste gate valve controls the supercharger impeller speed.

The action of the centrifugal blower is similar to that of the impeller of the internal supercharger. Air enters near the center of the blower and is conducted along the vanes to the blower exit. From here it passes through the inter-cooler, or air cooler, to the carburetor intake. As the waste gate valve closes, the exhaust back pressure is increased. The blower is so designed that when the exhaust back pressure reaches approximately 30" of mercury, an equal pressure is exerted on the carburetor intake. Thus a state of equilibrium is established, which is maintained by the gradual closing of the waste gate valve until the critical altitude is reached. Above this altitude the carburetor pressure begins to drop despite the fact that the waste gate valve is closed tightly and the blower is turning at top speed. This naturally results in decreased engine power output.

The action of the waste gate valve is controlled by an automatic unit which is actuated by the surrounding atmospheric pressure. The critical altitude, or the altitude density at which point the waste valve closes entirely, is in the neighborhood of 25,000 to 30,000 ft. This does not mean that the airplane cannot exceed this altitude, but simply means that normal engine power cannot be maintained above this point.

Air pressure decreases as altitude increases, so that at about 25,000 ft. the atmospheric pressure is in the neighborhood of 15" of mercury, thus in order to maintain a carburetor intake pressure of 30", the supercharger must compress the air in the ratio of about 2:1. In so doing the temperature of the air is raised to approximately 300° F. In order to obtain efficient carburetion this temperature is reduced by the inter air cooler to around 175° F.

Due to the increased stress placed upon high altitude flying, considerable experimental research is being devoted to the subject of supercharging, and it is likely that within the near future new or improved designs will be produced.

CHAPTER 7
FUEL SYSTEMS

The fuel system consists of the fuel tanks, the lines from the tanks to the carburetor, the strainers, hand pumps, engine-driven pumps, relief and by-pass valves, shut-off cock, primers, pressure gages and any other accessories which insure a proper supply of fuel to the engine. Strictly speaking, the carburetor is also a part of the fuel system, but this item is of such great importance that a separate chapter has been devoted to it.

The Civil Aeronautics Authority makes the following requirements with respect to the capacity and feed of the fuel system:

> "The fuel capacity shall be at least 0.15 gallons per maximum (except take-off) horsepower for which the airplane is certificated. Air-pressure fuel systems shall not be used. Only straight gravity feed or mechanical pumping of fuel is permitted. The system shall be so arranged that the entire fuel supply may be utilized in the steepest climb and at the best gliding angle and so that the feed ports will not be uncovered during normal maneuvers involving moderate rolling or side slipping. The system shall also feed fuel promptly after one tank has run dry and another tank is turned on. If a mechanical pump is used, an emergency hand pump of equal capacity shall be installed and available for immediate use in case of a pump failure during take-off. Hand pumps of suitable capacity may also be used for pumping fuel from an auxiliary tank to a main fuel tank."

The air pressure system referred to in the preceding paragraph was used at one time on airplanes in which the tanks were mounted below or at some distance from the carburetor. The gasoline was forced to the carburetor on to a separate gravity tank, by pumping air into the fuel tank, maintaining a pressure of several pounds per square inch. The two chief objections to this system are: first, in case of a leak in the line between the tank and the engine, the gasoline is sprayed all over the engine compartment - and in case of a crash such a leak would be almost sure to occur; and second, it is extremely difficult to keep the tanks airtight, particularly around the filler cap. Loss of air, of course, means that the pressure will not be maintained and accordingly the fuel will not be forced to the carburetor. The combination of the pronounced fire hazard with the almost equally dangerous possibility of a forced landing, due to loss of air pressure, caused the Dept. of Commerce to prohibit entirely the use of the air-pressure system. The gravity and mechanical pump systems will be discussed in detail below.

GRAVITY FUEL SYSTEMS

In the gravity system the fuel is fed to the carburetor by the force of gravity, and the tank, or tanks, must necessarily be well above the level of the carburetor. Such a system, incorporating two tanks, is shown in Fig. I. It should be borne in mind that this drawing is a diagram and that the parts are not necessarily to scale or in accurate relationship to each other. In other words, the fuel

lines may be led around any obstructions or arranged conveniently so that the shut-off cocks, strainer and any other accessories are within reach of the personnel. When two tanks are used, it is customary to conduct the fuel from each tank to a single "three-way"

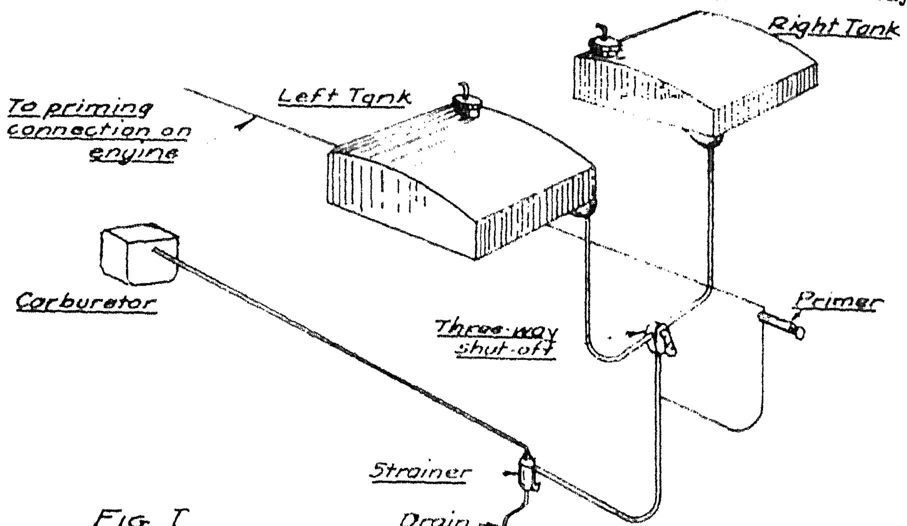


FIG. I

shut-off cock which, by proper setting of the handle, permits fuel to be used from either or both tanks or shuts both off completely.

The great advantage of the gravity system is its simplicity, with consequent reduction of weight and possible failure. No pumps, relief valves, or other mechanical parts are required. The piping is much more direct than in the type of system which uses a mechanical pump. The elimination of the items mentioned obviously decreases weight, expense, and the possibility of malfunctioning always associated with any mechanism. The chief disadvantage of the gravity system is that the tanks must be placed fairly high with respect to the carburetor. This practically eliminates the use of this system in low-wing monoplanes, since a tank in the fuselage is seldom high enough to provide a proper head or pressure at the carburetor. In the case of a biplane or high-wing monoplane, the tanks are usually installed above the fuselage, in the wing. Wing tanks are, as a rule, rather flat in proportion to their capacity. This is an inefficient shape. Furthermore, filling tanks in the wing is inconvenient and necessitates a great deal of climbing over the airplane with possible damage to the cowling or other relatively frail parts of the structure.

MECHANICAL PUMP SYSTEMS

A typical fuel system which embodies an engine-driven pump and which is recommended by Pratt & Whitney Aircraft is shown in Fig. II. In this system, the fuel is led from the tank through a strainer and a hand pump to the engine-driven pump, which is mounted directly on the engine and is driven through gears by the crankshaft. An engine-driven pump of this type usually requires "priming" by the hand

pump. This should not be confused with the priming of the engine itself. The mechanical pump is not capable of any large amount of suction until it is filled with fuel.

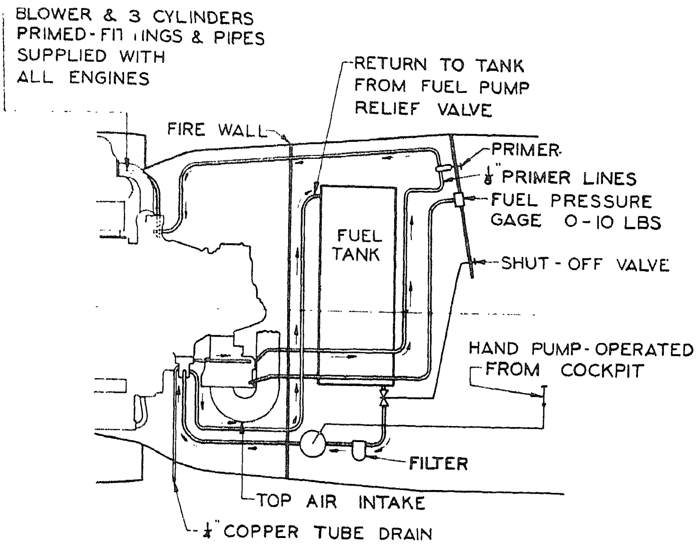


Fig. II

Mechanical pumps are capable of delivering far more fuel than the engine can burn. Accordingly, the fuel is pumped through a pressure relief valve. This valve is controlled by a spring, the compression of which may be adjusted. As soon as the pressure on the carburetor reaches a certain pre-determined amount, the valve opens and permits the excess gasoline to be taken back to the tank or to the feed line between the tank and the pump. In addition to the relief valve, a by-pass valve is provided which makes it possible to supply fuel to the engine by means of the wobble pump when the engine pump is not pumping. Such provision is necessary to insure a flow of fuel in case of failure of the engine pump and also to fill the carburetor prior to starting. The by-pass valve permits the fuel delivered by the hand pump to pass around the engine pump, through the relief valve, and thence to the carburetor. The two valves mentioned are frequently incorporated in the housing of the pump and will be discussed in detail later.

The advantages of the system just discussed are: first, a uniform pressure at the carburetor may be maintained, regardless of the level of the fuel in the tanks; second, the tank may be located in almost any position with respect to the engine; third, abnormal maneuvers are less likely to affect the flow of fuel. It is for these reasons that practically all military airplanes use this system. The disadvantages are: first, the increased weight of the system due to the incorporation of the pump and other accessories, and the extra piping needed for return lines; second, the ever-present possibility of mechanical failure, dirt in the relief valve, etc.

FUEL TANKS, CONSTRUCTION AND INSTALLATION

TANK CONSTRUCTION AND REPAIR

The Civil Aeronautics Authority makes the following requirements with respect to fuel tanks:

> "Each fuel tank shall be provided with either a sump and drain located at the point which is lowest when the airplane is in a normal position on the ground or outlets at the bottom of the tank provided with large mesh finger strainers. If a sump is provided, the main fuel supply shall not be drawn from the bottom of the sump. If no sump is provided the system drain shall be controllable from the pilot's compartment and shall act as a tank drain. Each tank shall be suitably vented from the top portion of the air space. Such air vents shall be so arranged as to minimize the possibility of stoppage by dirt or ice formation. When large fuel tanks are used, the size of the vent tubes should be proportioned so as to permit rapid changes in internal air pressure to occur and thereby prevent collapse of the tanks in a steep glide or dive. Tanks of 10 gallons or more capacity shall be provided with internal baffles unless suitable external support is provided to resist surging.
>
> "Fuel tanks shall be capable of withstanding an internal test pressure of $3\frac{1}{2}$ pounds per square inch without failure or leakage. Fuel tanks of large capacity which have a maximum fuel depth greater than 2 feet shall be investigated for the pressure developed during the maximum limit acceleration with full tanks. Tanks shall be so designed, and the rivets or welds so located, as to resist vibration failures or leakage.
>
> "A satisfactory gauge shall be so installed on all airplanes as to readily indicate to a pilot or flight mechanic the quantity of fuel in each tank while in flight. When two or more tanks are closely interconnected and vented, and it is impossible to feed from each one separately, only one fuel-level gauge need be installed. If a glass gauge is used, it shall be suitably protected against breakage.
>
> "All filler openings in the fuel system shall be plainly marked with the capacity and the word 'fuel'. Provision shall be made to prevent any overflow from entering the wing or fuselage."

The sump referred to in the requirements given above is either a marked depression or else a small extension added to the bottom of the tank. Its purpose is to provide a low point in which any dirt or water may collect, and from which foreign matter may be drained by means of a drain cock or plug. It is for this reason that the main fuel supply may not be drawn from the bottom of the sump. In the absence of a sump the system must be so designed that this foreign matter may be readily drained by the pilot, either on the ground or in the air.

By "surging" is meant a sudden rush of fuel from one end or side of the tank to the other, caused by abrupt maneuvers or severe air bumps. Unless the tank is built to resist this sudden strain, leaks are likely to develop. Surging may be prevented by breaking

the tank into a number of compartments by means of "baffles" or walls of metal from one side of the tank to the other. The baffles are perforated so as to allow the gas to flow freely but not abruptly through them and serve the double purpose of retarding the flow until it is below the danger point and of reinforcing the tank.

In performing a tight bank or in pulling out quickly from a steep dive, there is a great increase in the load carried by all parts of the structure, due to the centrifugal force. This increase is referred to as "acceleration" and is measured in terms of gravity. Thus, an acceleration of "3g" means simply that the effective weight of every item in the airplane is increased three times. Under this condition the bottom of the gas tank must carry not merely the normal weight of a fuel but three times this weight. When it is remembered that an acceleration of 7g or more may be encountered in violent maneuvers, the reason for the requirement referred to is readily understood.

Brass and Terneplate Tanks - In some of the early airplanes fuel tanks were made of brass. This material has been discontinued on account of its cost and weight. Terneplate, however, which is sheet steel "tinned" on both sides, is still found in a few of the inexpensive sport ships. Its advantages are its low cost and the simplicity of construction and repair. Its chief disadvantage is its weight.

Terneplate tanks are riveted and soft-soldered at the seams. A lock joint may be used, in which case only a few rivets are required. Such a joint is shown in Fig. I. Repairs are extremely simple. If a leak occurs at a joint it may be readily stopped by running a little soft solder over the spot with a soldering iron. Caution: Under no circumstances should a torch be used on a tank which has ever contained gasoline, except with special provisions, to be explained later. If the leak is in the side, bottom or top of the tank, a patch must be put on as described in the following paragraph.

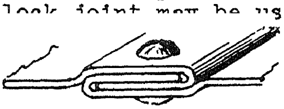


FIG. I

Making Tank Patches - If the tank has been damaged in some flat section, such as on the sides, bottom, or top, it may be repaired by using a soldered, a riveted, or a machine-screwed patch. The soldered patch can be used to repair small holes. If the hole is much larger than 2" in diameter, a riveted patch should be used. If it is impossible to buck the rivets from the inside, then, of course, a machine-screwed patch is used.

The first step in making a patch is to clean the damaged area of the tank to facilitate both a thorough inspection and a satisfactory repair. If the injury is simply a crack, it was probably caused by the metal having been strained at that point. To prevent a continuation of the cracking after the repair has been made, a small hole should be drilled at each end of the crack. In some cases it may be advisable to remove a small portion of the tank material to relieve any existing strain. If the damage has been caused by chafing, enough of the tank material should be removed so that no part of the chafed area remains. If the tank has been punctured, enough

metal should be removed to form the opening into a definite shape: square, rectangular, or, preferably, circular. If there are any dents near the damaged portion, they should be straightened. Very often this can be done by inserting one prong of an L-shaped bucking iron into the hole and supporting the dented area from beneath, gently tapping the outside with a wooden mallet. Caution: Too much hammering will stretch and thin the metal and cause it to buckle.

If a copper patch is to be used it should be of metal which is one or two gages heavier than the tank material and should be sufficiently large to extend from 1/2" to 5/8" beyond the outside of the hole all around. The edges of the patch should be feathered, or bevelled with a file, as shown in Fig. II.

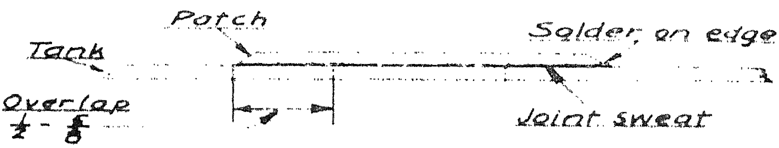


FIG II - SOLDER PATCH

Before a soldered patch can be applied, both the under edges of the patch and the area on the tank over which the patch is to be placed, should be tinned. For more specific directions on soldering see Chapter IV. It is well to remember, in this connection, that it requires considerable heat to tin any portion of the tank as the heat from the soldering iron is quickly conducted away from the portion being tinned. For this reason it is desirable to use a three or four pound iron. After the tank and the patch have been thoroughly tinned and all excess solder wiped off with a clean cloth, a very thin, evenly distributed coat of solder should be applied. After this has cooled, the patch should be placed on the tank, taking care to center it over the hole. The use of pencil lines to serve as a centering guide is recommended. The actual attaching of the patch is accomplished by "sweating" the joint. This is done by holding the patch onto the tank in the proper position with a stick and then holding the hot soldering iron on the top of the patch until the solder under the patch is thoroughly melted. To com-

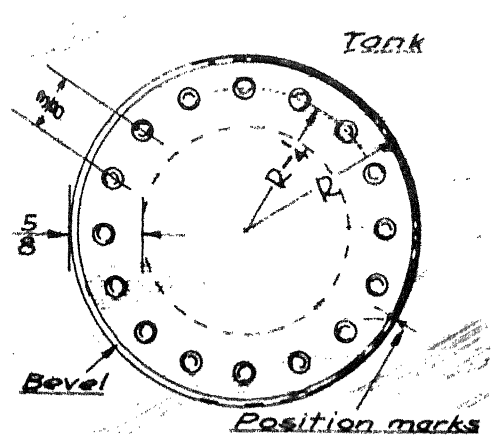


FIG III - RIVET PATCH

plete the job solder is run around the feathered edge of the patch.

If a riveted patch is to be used it should be of the same material and gage as the tank and should be large enough to overlap on all sides at least 5/8". The center line for the rivet spacings should be 1/4" from the edge of the patch and the rivets should be spaced 3/8" apart. These locations should be center punched and drilled for 1/8" rivets. See Fig. III. The rivets should be of material the same as or harder than the tank. After the patch has been drilled it should be carefully centered over the hole in the tank. A hole, slightly less than 1/8" in diameter, should be drilled in the tank, using the patch as a guide. A small Parker Kalon metal screw is driven in this hole to prevent the patch from slipping. A second hole is then drilled and the patch secured with another screw, after which the rest of the holes may be drilled full size. Before removing the patch, a mark should be placed on the rim of the patch and a corresponding mark directly opposite on the tank. This is so the patch may be replaced in exactly the same position. The patch may now be removed and used as a template in making a gasket of vellumoid or flannel. The patch is now ready to be riveted in place. Naturally the rivets will be inserted with the head on the inside of the tank and must be carefully bucked while being riveted.

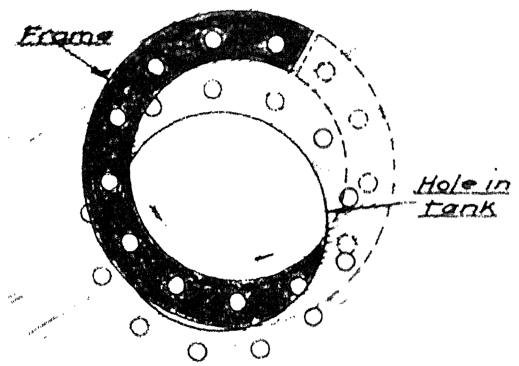
Machine-screwed patches are the most difficult to make but are often the only type it is possible to use. The patch itself should be laid out in the same manner as for the riveted patch, with the exception that the drilled holes are either 5/32" or 3/16" to fit either a #8 or #10 machine screw, respectively. If a #10 machine screw is used it is not necessary to space the holes closer than 1/2". The patch should serve as a guide for drilling the holes in the tank as described above.

Next a frame should be made to hold the machine screw nuts. This frame should be of thin gage steel or copper, from 1/32" to 1/16", and is made to the same outside dimension as the patch with a frame thickness of 1/2". The patch should also be used as a guide in drilling the holes in the frame, and the drilling position marked so that the same position can be used when the patch is assembled. After the frame has been drilled, nuts, of the proper size to fit the screws being used, should be soldered in line with the holes.

Considerable difficulty is often experienced in soldering the nuts to the frame. However, if the following procedure is followed carefully the job will be simplified. First one side of the frame is tinned and then coated with a thin film of solder. Next the under side of the nuts are tinned, taking care not to run the solder into the threads. The actual soldering of the nuts to the frame is best done by first inserting the screws in the frame from the untinned side and starting the nuts on each screw. By this means perfect alignment is assured and in addition, when the frame is held in a horizontal position, the weight of the screws holds the tinned surfaces together. With the frame supported in this position, the nuts may be soldered in place by holding a clean soldering iron on the top of the nut until the solder between the nut and the frame is melted, or by heating the entire frame with a torch.

After the nuts are soldered securely, the screws should be removed and the threads in the nuts cleaned with a tap. The ends of machine screws may then be ground to a slight point, as an aid in starting them when the patch is assembled. If the threads are tight in the nut they may be cleaned with a die.

The frame is inserted into the tank by first cutting the frame at one point and starting one end in the tank, then turning the frame around until the entire frame is inside. Naturally it must be held in position with a finger until one screw is inserted, the patch meanwhile being swung to one side to allow room for the finger. This procedure is illustrated in Fig. IV.



Inserting frame in tank
FIG. IV

The patch is now screwed in place, using a suitable gasket coated with shellac on both sides. Care should be taken to make sure that the marks on the tank, frame and patch coincide. The machine screws may be safetied by soldering their heads to the patch.

Another form of machine-screwed patch can be used, although it is not quite so neat. This patch is made in the manner described above but the machine screws are soldered to the frame so that when the frame is inserted in the tank the screw shanks extend outside. The gasket and patch are placed over the screws and secured with nuts. The nuts may be safetied with a lock washer or a small drop of solder. Many mechanics consider this type superior to that in which the nuts are soldered to the frame.

Aluminum Tanks - The great majority of fuel tanks are made of aluminum, torch-welded at the joints. Aluminum tanks weigh only about half as much as terneplate tanks of equal capacity. Furthermore they do not rust, as terneplate may after long use. The chief disadvantage of aluminum tanks is that they are rather hard to repair without special equipment. It is possible to mend a leak in the wall of the tank by using a steel frame such as that described in the preceding paragraph. However, a repair of this type should be used only until there is an opportunity to remove the tank and have a patch welded in place.

It is of course necessary to use a torch in welding on a patch or in making repairs at a joint. This work should be done only by an expert aluminum welder. The tank should be thoroughly blown out with live steam, and even then there is a possibility of an explosion. Live steam is used because its heat tends to evaporate any gasoline

and its pressure to blow out the fumes. An alternative method is to fill the tank completely with carbon tetrachloride (fire extinguisher liquid) and drain it. The importance of these precautions cannot be over-emphasized, as cases have been known of tanks which had been empty for six months, and which had been washed out with water, blowing up when the torch was applied. After repairs have been made, the tank should be thoroughly washed out with gasoline to remove any traces of the carbon tetrachloride or condensed steam.

Duralumin Tanks - Duralumin, or strong aluminum alloy, has about twice the strength and stiffness of the aluminum ordinarily used in welded tanks. Hence it is natural that some manufacturers prefer to use it, since the thickness of the metal, and consequently the weight of the tank can be reduced. However, duralumin presents difficulties with respect to welding, as the heat of the torch destroys its strength properties and at the same time renders it much more susceptible to corrosion. Accordingly, most duralumin tanks are riveted at the joints. To prevent leakage, a special seam compound, not affected by gasoline, is used where the lap is made. In addition some sort of gasket material, usually strips of tape or canton (cotton) flannel, is often laid along the seam, between the sheets, before they are riveted together. This method of construction is more expensive than welding; thus the situation resolves itself into a compromise between reduced weight and increased expense, as is so frequently the case in aircraft design.

Leaks at the seams of dural tanks may be repaired by removing the rivets in the affected area, forcing additional seam compound into the joint with a knife blade, and riveting again with the next larger size of rivet. If no rivets are available, machine screws may be used as a temporary measure. Leaks in the wall of the tank must be repaired either by riveting on a patch (if the damage is near enough to the filler neck to permit the use of a bucking tool), or by using a steel ring with machine screws soldered to it as previously described.

Stainless Steel Tanks - Tanks made of stainless steel are probably the most expensive type. However they have many advantages. The material is highly resistant to corrosion, is extremely strong, (about three times as strong as duralumin) and, if need be, may be soldered readily by using the proper soldering flux, as described previously. Stainless steel tanks are ordinarily spot-welded at the joints. Spot-welding consists of holding the metal sheets together by means of two electrodes and passing a current of electricity through the electrodes and the sheets. The metal is fused together at one spot - hence the name of the process. By overlapping these spots, a continuous weld is produced, which is absolutely gas-tight and extremely strong. The welding may be done with great rapidity by special machines, and probably for this reason is often called "shot welding."

Stainless steel tanks may be repaired just as those made of terneplate - that is, by soldering on a patch of the same material with soft solder, or by riveting or bolting on a patch. Leaks seldom occur at the joints, but if they do, may be stopped by the use of solder, applied with an iron.

INSTALLATION OF FUEL TANKS

The requirements of the Civil Aeronautics Authority with respect to the installation of fuel tanks are as follows:

> "No fuel tank shall be placed closer to an engine than the remote side of a fire wall. At least one-half inch clear air space shall be allowed between the tank and fire wall. Spaces adjacent to the surfaces of the tank shall be ventilated so that fumes cannot accumulate or reach the crew or passengers in case of leakage. If two or more tanks have their outlets interconnected they shall be considered as one tank and the air space in the tanks shall also be interconnected to prevent differences in pressure at the air vents of each tank of sufficient magnitude to cause fuel flow between the tanks. Mechanical pump systems shall not feed from more than one tank at a time except by special ruling from the Secretary."

When installing tanks, some sort of padding must always be provided between the tank and the supports or "tank bearers", and likewise between the tank and the retaining or "hold-down" clamps or straps. This padding prevents chafing and damage to the metal from which the tank is made, and usually consists of felt strips wide enough to cover the entire support and 1/8" to 1/4" thick. The felt is usually attached either to the support or the tank by means of shellac, which keeps the padding from working out of place.

Tanks are commonly held in place by a stiff bar extending entirely across the tank and bolted down at the ends, by screwed-down clamps around the edges of the tank, or by straps extending up the sides and over the top and tightened by a turnbuckle in some accessible location. An illustration of this last type of fastening is

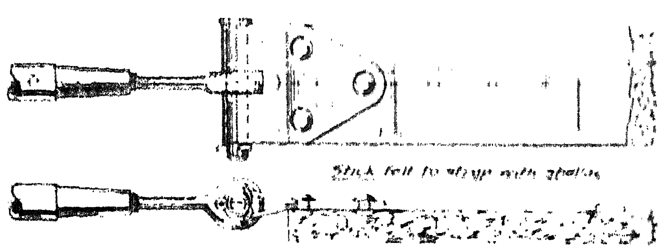


Fig I

seen in Fig. I. Sometimes a cable, suitably padded, is used instead of the strap shown in this illustration. Needless to say, the turnbuckle or other means of adjustment should be securely safetied.

FUEL LINES, FABRICATION AND INSTALLATION

The requirements of the Civil Aeronautics Authority with respect to fuel lines are as follows:

> "All fuel lines and fittings shall be of sufficient size so that under the pressure of normal operation the flow is not less than double the normal flow required for take-off engine power. A test for proof of compliance with this requirement shall be made. All fuel lines shall be so supported as to prevent excessive vibration and should be located so no structural loads can be applied. Bends of small radius and vertical humps in the lines shall be avoided. Copper fuel lines which have been bent shall be annealed before installation. Parts of the fuel system attached to the engine and to the primary structure of the airplane shall be flexibly connected thereto. Flexible hose connections and fuel lines shall have metal liners or the equivalent. Fittings shall be of a type satisfactory to the Secretary."

The size of the tubing required for any installation may ordinarily be determined by noting the connection on the carburetor. The reason for requiring that the piping be supported so as to prevent vibration is that copper (or any other material from which fuel lines are likely to be made) will tend to harden, crystallize, and ultimately crack, as a result of vibration. Bends of small radius may cause the same trouble, also they tend to restrict the flow of fuel. Vertical humps in the line, whether the humps are up or down, are likely to produce an air or vapor lock and cut off the flow of fuel at a crucial moment. Copper lines are annealed after bending because any working of copper causes it to harden, and it is desirable to have the metal as soft as possible when it is originally installed. The process of annealing is described later. The flexible connections referred to may be either special gasoline hose of rubber and fabric construction or corrugated metal piping. Both of these will be discussed in more detail later.

Types of Fittings - A pipe fitting is a small metal part used for connecting pieces of tubing to a tank, a carburetor, an accessory (such as a pump), or to another piece of tubing. Classifying fittings with respect to the manner in which they are attached to the tubing, there are three main types, known respectively as flared fittings, compression fittings, and soldering fittings. Each of these is subdivided into a large number of designs, such as elbows (frequently called "ells"), unions, tees, nipples, reducing couplings, etc. A number of such designs are shown in Fig. I. A male end is one which is threaded on the outside, a female end is threaded on the inside. The threads may be pipe threads, which are tapered so that they tighten as they are screwed in and which make the connection to the carburetor, accessory, tank, or to another fitting. Or they may be machine threads, which receive the coupling nut or union nut.

Pipe fittings were originally designed for heavy iron water or gas pipe, in which the size of the pipe is designated with respect to its inside diameter. The tubing used for fuel and oil lines in aircraft is designated by its outside diameter. As a result there is frequently some confusion in the beginner's mind as to the size of the fittings used on the various sizes of copper, aluminum or

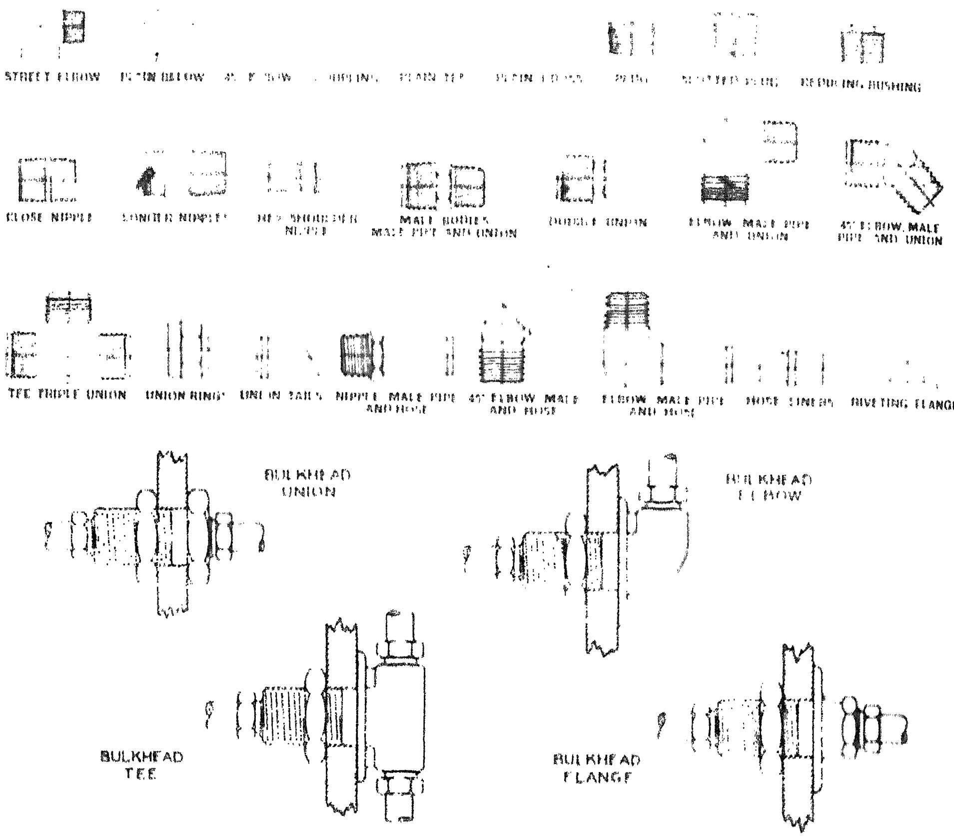
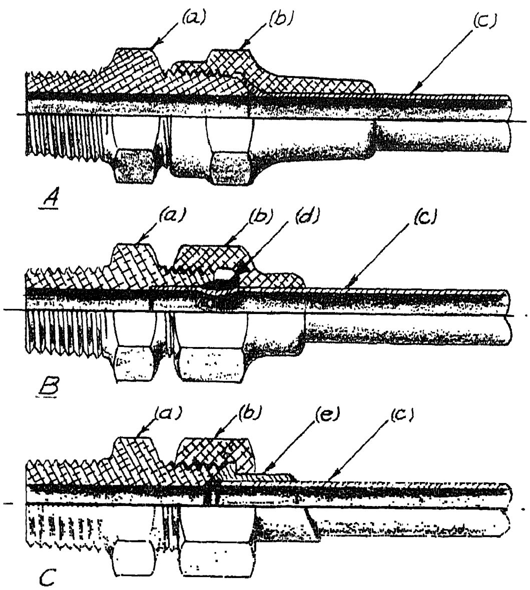


Fig I

duralumin tubing. The table below gives the outside diameter of the most common sizes of tubing used in fuel and oil lines with the corresponding size of the pipe fitting required.

Tubing diameter	Size of pipe fitting
1/8"	1/8"
3/16"	1/8"
1/4"	1/8"
5/16"	1/8"
3/8"	1/4"
1/2"	3/8"
5/8"	1/2"
3/4"	3/4"
7/8"	3/4"
1"	1"
1-1/4"	1"

However, it should be remembered that this table refers only to the pipe thread and that the diameters of the sleeves and nuts discussed below must be such as to fit the tubing properly.



In Fig. II the three main types of fittings as manufactured by the Lunkenheimer Co., are illustrated in half-section. Each view shows a union with a pipe thread on one end and a machine thread, to receive the coupling nut, on the other. The outside of the large portion of the union is hexagonal, as is also the union nut. The size of the hex is such as to fit a standard open end wrench. The flared fitting is shown in illustration A, the compression fitting in B, and the soldering fitting in C. In all illustrations the union is labelled (a), the nut (b), and the pipe or tubing (c). The compression fitting, B, seals the joint by means of the wedge cone, (d), which crushes the tubing slightly as the nut is screwed down. This fitting is objected to by some on the ground that the tubing is likely to crack at the point where it is compressed. The soldering fitting uses a tail, (e), which is silver-soldered to the tubing. This type of fitting is considered the most reliable of all, but is more difficult to make because of the silver-soldering, and cannot be used on aluminum or duralumin tubing since these metals cannot be soldered satisfactorily.

Fig. III shows sections of flared fittings manufactured by the Parker Appliance Co., the standard type being illustrated in A and the "triple tube" type in B. The triple tube fitting is used where it is necessary to make connections in close quarters, since the tubing extends a much shorter distance into the fitting and hence can be more readily removed.

BENDING AND FITTING FUEL LINES

The tubing from which fuel lines is made may be copper, aluminum or duralumin. If either of the last two is used, the fittings must be of the flared or compression type. Regardless of the material from which the tubing is made, it should be in its dead soft condition before any work is done on it, and, as previously mentioned, copper should also be annealed after it has been bent and before it is installed. Copper is the heaviest of the three materials mentioned, but probably the most reliable, and furthermore, may be soldered. Duralumin is the lightest, for although its weight per

cubic inch is slightly more than that of aluminum, it is much stronger, thus permitting the use of a lighter gage.

Making Patterns - Except in the case of large production orders the fuel lines are usually bent and fitted "on the job"; that is, without accurate drawings of the individual pieces. Unless the bend is extremely simple, a pattern is usually essential. Such a pattern is usually made from soft brass or aluminum rod, about 3/16" in diameter. If no such material is available, discarded tubing, preferably not more than 1/4" in diameter, may be used.

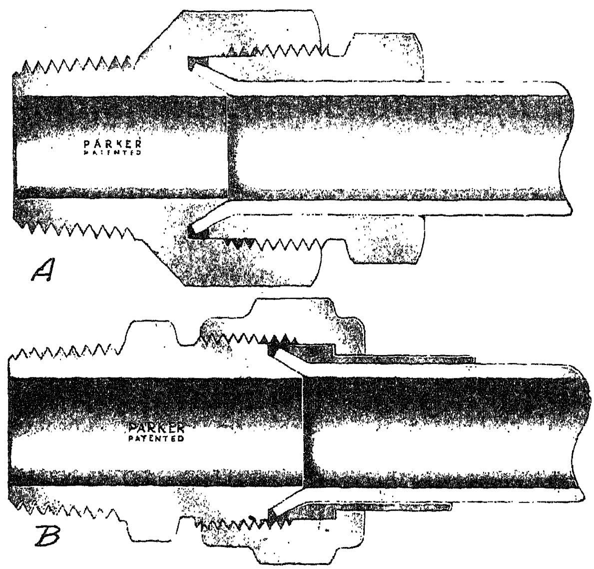


FIG. III

Before bending the pattern an excellent plan is to mark it at intervals of 6", 3", or 1", depending on the circumstances. After it has been bent and fitted, these marks may be counted and the length of the tubing necessary to makr the finished piece closely determined. This practice eliminates a great deal of waste.

The pattern material should be bent so that it fits accurately where the tubing is to be installed. Great care should be taken to see that the ends are directly in line with the ends of the parts to which the piece is to be connected, as otherwise there will be difficulty in assembling the joints.

Preparing Tubing for Bending - As previously stated, tubing which is to be bent must be in a dead soft condition. If the material is duralumin, it may be obtained from the manufacturer in the fully-annealed state. If it is not, it must be annealed in a regular furnace. As this kind of annealing is a form of heat treatment, it does not come within the scope of the mechanic's duties. The dead-soft requirement also applies to aluminum, though a fair job of softening this material may be accomplished by heating it with a gasoline blow torch until it will char soft wood rubbed against it, then allowing it to cool slowly.

Copper tubing is annealed by heating it to a dull red and quenching it in water. However, the quenching should not be attempted unless the quenching tank is large enough to allow the entire piece to be immersed at one time. If such a tank is not available,

the metal should simply be allowed to cool. In the latter case, the annealing is not as thorough as when proper quenching may be done, but the tubing will be soft enough to bend easily and will at least be uniform. Quenching only part of the piece at a time is undesirable, as some portions will be softer than others. Another method of annealing is to use an oxy-acetylene torch set so that an excess of acetylene is being supplied. The flame is passed along the tube until it is thoroughly and evenly blackened, or smoked. The flame is then adjusted properly and the carbon deposit on the tube burned off.

The next step is to remove all kinks or small bends from the tubing. These are not likely to be found in duralumin tubing, but frequently occur in copper or aluminum. The tubing should be straightened as much as possible by the use of the hands alone. It should then be laid on a perfectly flat smooth wooden surface and rapped sharply with a flat piece of wood or a wooden paddle, meanwhile rolling it back and forth. This rolling and rapping should be continued until the tubing is perfectly straight. Another method is to clamp the tubing between blocks which are grooved so that they exactly fit it. Large factories are usually equipped with straightening machines which eliminate both of the methods just mentioned, but such machines are seldom available to the field or service mechanic.

If the tubing is to be bent without the assistance of any of the special equipment described in succeeding paragraphs, and if its diameter is more than 3/16", it must be filled with some material to prevent buckling and flattening where the bends are made. There are three such materials in common use: sand, rosin and bending alloy. This last is an alloy of lead, tin and other metals and melts at a temperature of 160° to 180°F., depending upon the exact composition.

Sand is, of course, the most readily obtainable of these three and will be found satisfactory in most cases. The procedure is simple. After the tubing has been straightened, one end is securely plugged with a wooden plug or an ordinary cork bottle-stopper; or else the end is mashed flat in a vise, doubled back over itself and again squeezed tight, as shown in Fig. I. Fine, sifted sand is poured into the other end through a funnel. As the sand is being poured in, the tubing should be tapped gently with a flat paddle to make the sand pack as tightly as possible. When the tube has been entirely filled, the open end is plugged, care being taken to leave no appreciable unfilled space. The bends are then made, as discussed later, the plugs removed or the ends of the tubing cut off, and the interior of the tube cleaned thoroughly, preferably by rinsing with water and drawing a clean rag through the entire length by means of a wire. If copper tubing is used, it should be re-annealed. The ends are then cut properly, as described in a succeeding paragraph.

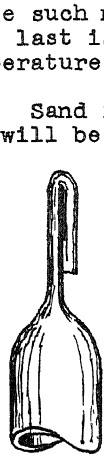


FIG. I

If the filler is rosin, one end of the tube should be plugged or flattened as mentioned above. The rosin is melted in a clean

ladle and the tubing heated by means of a gasoline blow-torch so that the rosin will not solidify without completely filling the tube. The rosin is then poured in and allowed to harden. The tube should be held at an angle of about 45^{o} while it is being filled so that the rosin will run down one side of the inner wall. After the bends have been made, the rosin is melted out by means of a torch or other source of heat, great care being taken to have the temperature high enough to melt every particle of the filler. The heat should be applied at the open end first. If the tube is heated in the central portion while the rosin is still hard at the ends, an explosion may occur. In the case of copper tubing, this melting-out process also serves to anneal the metal.

The most satisfactory filler for bending tubing is the bending alloy previously mentioned. The Parker Appliance Co. has developed an alloy, called "Tuballoy", which is especially designed for use in the fabrication of fuel and oil lines. In making bends which are complicated or of small radius, this material is particularly desirable. Although it is somewhat more expensive than sand or rosin, it may be used over and over indefinitely. The procedure when using it is much the same as that followed with rosin. The alloy should be melted in a clean ladle set in boiling water, in the fashion of a double boiler, to prevent overheating. The tubing is plugged at one end and filled with boiling water. The Tuballoy is then poured into the tube, forcing the water out. This insures the alloy being kept hot and the tubing being completely filled. The tubing is then held under cold running water, or immersed, to chill the alloy. The bending operation is performed just as in the case of the rosin, and the Tuballoy removed by heating the tube in steam or boiling water. Tuballoy sometimes shows a tendency to tin the inside of copper tubing. This may be prevented if the inside of the tube is oiled with engine oil before filling.

Bending and Finishing Tubing - After the tubing has been properly filled, it should be bent to fit the pattern accurately. This work may be done with the hands alone except in the case of very large tubes. However, it is highly desirable to provide bending blocks with suitable radii. These blocks are made of wood, cut to the proper curvature and preferably grooved to fit the tubing which is being bent. Particular care should be taken to keep the tubing straight between bends, as otherwise a sloppy appearance will result. In other words, after the job has been finished the shape should consist of a series of arcs connected by straight lines, with no kinks or irregularities between the arcs. In general, the radius of bends should be not less than three times the diameter of the tubing.

After the tubing has been bent, the ends must be cut to fit accurately in place and the cut must be perfectly square. The cut may be made with a hacksaw or with a special tubing cutter. If the hacksaw is used, a block of wood with a V-shaped groove will be found helpful in holding the tube while sawing. Fig. II shows a tube cutter manufactured by the Parker Appliance Co. To use this tool, the tubing is laid on the two rollers and the cutting wheel screwed down lightly against it. The cutter is

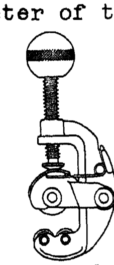


FIG. II

then rotated around the tube in a counter-clockwise direction, meanwhile maintaining a light, even pressure on the cutting wheel by means of the screw adjustment. It is usually desirable to cut the tubing before the filler has been melted out, so that if minor bends are necessary after cutting there will be no danger of buckling. When the ends have been cut, the piece should be tried in place to make sure that it will fit. This check having been made, the filler may be removed as previously instructed.

When the inside of the tube has been cleaned, any burrs on the ends should be removed with a pocket knife or machinist's scraper. The outside of the tube should then be polished with steel wool or fine emery cloth, taking great care to allow no steel chips or dust to enter the tube. Identifying bands of color may then be painted two or three inches from each end. Most airlines have their own system of colors, but as a rule the fuel lines are marked with red bands, oil lines with yellow, and water or air with white. After the marking paint has dried, the entire outside should be given a coat of varnish, Lionoil or clear lacquer.

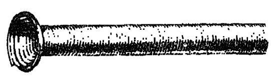


FIG. III

Bending Devices - There are several devices available which make it possible to bend tubing without the necessity of filling it. The simplest of these is merely a coil of steel wire, shown in Fig. III. The inside diameter of the coil is, of course, the same as the outside diameter of the tubing. In making the bend, the coil is slipped on the tube which is then shaped with the hands to the proper curvature, with or without the use of a bending block. After the bend is made, the coil is removed by twisting and pulling it at the same time, against the spiral to avoid unwinding the spring.

The use of the Parker Hand Tube Bender is illustrated in Fig. IV. In order to understand the following instructions, assume that the bender is laid on the bench with the marked side of the sheave block up, the round handle extending to the left, and the flat handle to the right, approximately in the position shown in B. The flat or right handle is then swung up and toward the left as far as it will go, and the tube retaining clip lifted. The bender will then appear as in A. The tubing is dropped into position as shown in the same illustration. The retaining clip is dropped over the tube and

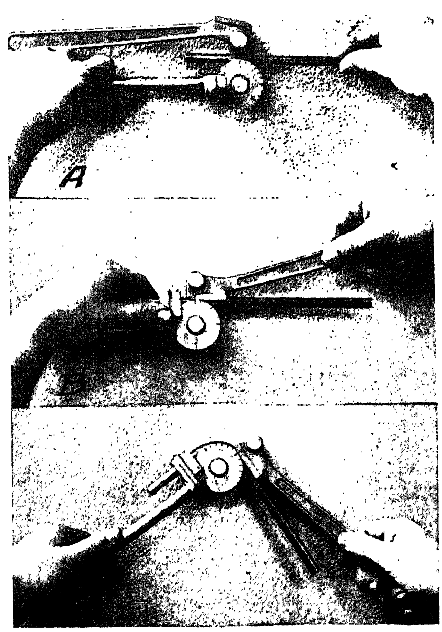


FIG. IV

ladle and the tubing heated by means of a gasoline blow-torch so that the rosin will not solidify without completely filling the tube. The rosin is then poured in and allowed to harden. The tube should be held at an angle of about 45° while it is being filled so that the rosin will run down one side of the inner wall. After the bends have been made, the rosin is melted out by means of a torch or other source of heat, great care being taken to have the temperature high enough to melt every particle of the filler. The heat should be applied at the open end first. If the tube is heated in the central portion while the rosin is still hard at the ends, an explosion may occur. In the case of copper tubing, this melting-out process also serves to anneal the metal.

The most satisfactory filler for bending tubing is the bending alloy previously mentioned. The Parker Appliance Co. has developed an alloy, called "Tuballoy", which is especially designed for use in the fabrication of fuel and oil lines. In making bends which are complicated or of small radius, this material is particularly desirable. Although it is somewhat more expensive than sand or rosin, it may be used over and over indefinitely. The procedure when using it is much the same as that followed with rosin. The alloy should be melted in a clean ladle set in boiling water, in the fashion of a double boiler, to prevent overheating. The tubing is plugged at one end and filled with boiling water. The Tuballoy is then poured into the tube, forcing the water out. This insures the alloy being kept hot and the tubing being completely filled. The tubing is then held under cold running water, or immersed, to chill the alloy. The bending operation is performed just as in the case of the rosin, and the Tuballoy removed by heating the tube in steam or boiling water. Tuballoy sometimes shows a tendency to tin the inside of copper tubing. This may be prevented if the inside of the tube is oiled with engine oil before filling.

Bending and Finishing Tubing - After the tubing has been properly filled, it should be bent to fit the pattern accurately. This work may be done with the hands alone except in the case of very large tubes. However, it is highly desirable to provide bending blocks with suitable radii. These blocks are made of wood, cut to the proper curvature and preferably grooved to fit the tubing which is being bent. Particular care should be taken to keep the tubing straight between bends, as otherwise a sloppy appearance will result. In other words, after the job has been finished the shape should consist of a series of arcs connected by straight lines, with no kinks or irregularities between the arcs. In general, the radius of bends should be not less than three times the diameter of the tubing.

After the tubing has been bent, the ends must be cut to fit accurately in place and the cut must be perfectly square. The cut may be made with a hacksaw or with a special tubing cutter. If the hacksaw is used, a block of wood with a V-shaped groove will be found helpful in holding the tube while sawing. Fig. II shows a tube cutter manufactured by the Parker Appliance Co. To use this tool, the tubing is laid on the two rollers and the cutting wheel screwed down lightly against it. The cutter is

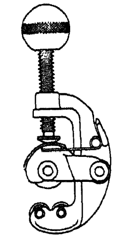


FIG. II

then rotated around the tube in a counter-clockwise direction, meanwhile maintaining a light, even pressure on the cutting wheel by means of the screw adjustment. It is usually desirable to cut the tubing before the filler has been melted out, so that if minor bends are necessary after cutting there will be no danger of buckling. When the ends have been cut, the piece should be tried in place to make sure that it will fit. This check having been made, the filler may be removed as previously instructed.

When the inside of the tube has been cleaned, any burrs on the ends should be removed with a pocket knife or machinist's scraper. The outside of the tube should then be polished with steel wool or fine emery cloth, taking great care to allow no steel chips or dust to enter the tube. Identifying bands of color may then be painted two or three inches from each end. Most airlines have their own system of colors, but as a rule the fuel lines are marked with red bands, oil lines with yellow, and water or air with white. After the marking paint has dried, the entire outside should be given a coat of varnish, Lionoil or clear lacquer.

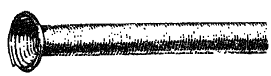


FIG. III

Bending Devices - There are several devices available which make it possible to bend tubing without the necessity of filling it. The simplest of these is merely a coil of steel wire, shown in Fig. III. The inside diameter of the coil is, of course, the same as the outside diameter of the tubing. In making the bend, the coil is slipped on the tube which is then shaped with the hands to the proper curvature, with or without the use of a bending block. After the bend is made, the coil is removed by twisting and pulling it at the same time, against the spiral to avoid unwinding the spring.

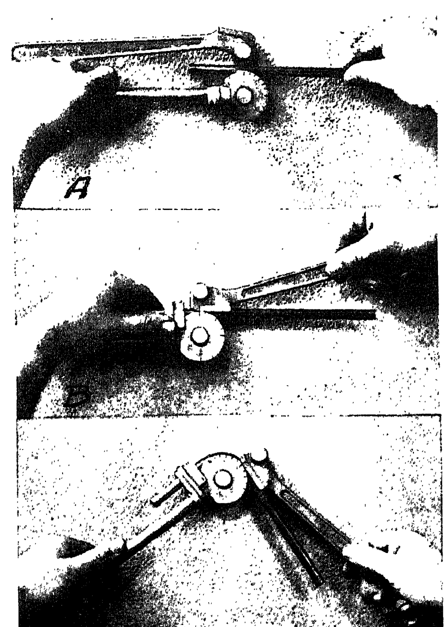


FIG. IV

The use of the Parker Hand Tube Bender is illustrated in Fig. IV. In order to understand the following instructions, assume that the bender is laid on the bench with the marked side of the sheave block up, the round handle extending to the left, and the flat handle to the right, approximately in the position shown in B. The flat or right handle is then swung up and toward the left as far as it will go, and the tube retaining clip lifted. The bender will then appear as in A. The tubing is dropped into position as shown in the same illustration. The retaining clip is dropped over the tube and

the flat handle pulled around to the position shown in B. The mark on the block end of the flat handle will line up with the zero degree mark on the sheave block. The flat handle is then pulled around as shown in C until the mark on the block end of the flat handle reaches the desired degree mark on the sheave block. (In C this is ninety degrees.) To remove the bent tube, the flat handle and clip are brought back to the position shown in A, and the tube lifted out.

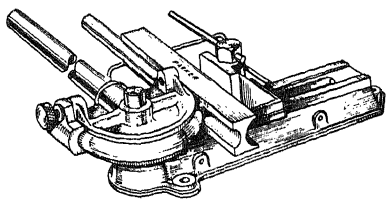


FIG. V

Where a great many tubes are to be bent, especially in production work, where there are many pieces with the same form, a bench bender of the type shown in Fig. V is often used. The general principles involved in its use are the same as in the hand bender. However, the average engine mechanic is not likely to have such a machine available.

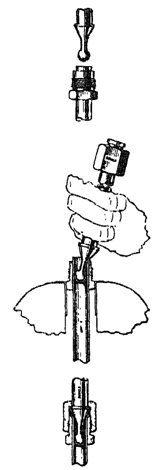


FIG. VI

Attaching Flared Fittings - The next step in making fuel lines consists of attaching the fittings. The Parker Appliance Co. manufactures a number of tools for flaring tubing for the flared type of fitting. In Fig. VI are shown the successive operations in flaring a tube with a Ball Type flaring tool. The nut is slipped on the tube and the tube allowed to extend about 1/16" beyond the nut, which is then gripped in a vise. The flaring tool is inserted to the point where its taper begins. The tool is then rotated inside the tube, pressing outward and downward until the tube is flared to fit the nut. A slow circular motion with a firm even pressure should be maintained. The operation should not be continued after the tube has been flared to fit the nut, as the tubing may be thinned unnecessarily. After the flaring has been completed, the outside nut which is a part of the flaring tool may be screwed down on the tubing nut to produce a better fit. In the case of the triple tube coupling, the sleeve, as well as the nut must be put on before the flaring is begun. Another type of flaring tool is shown in Fig. VII. This model is known as a Combination Flaring Tool since it can be used on a number of different sizes of tubing. In using this tool, the tubing is clamped securely in the flared hole which fits it, the flaring pin is set over the tube and struck a number of light blows with a hammer until the tubing is properly flared. It is desirable to rotate the flaring pin

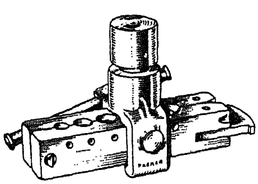


FIG. VII

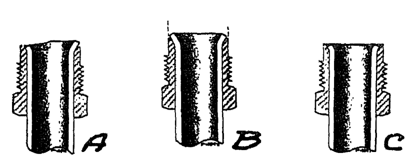


FIG. VIII

while it is being struck. Fig. VIII-A shows a correct flare. In B, the end of the tubing has not been cut square and an unsatisfactory job has resulted. In C, too little tubing was allowed to extend beyond the nut, and the flare is too short, with the possibility of causing leaks or of the tube pulling out if any force is exerted upon it.

Attaching Compression Fittings - The compression type of fitting is probably the easiest to attach, but, as previously stated, is the least satisfactory of the three, from the standpoints both of reliability with respect to leaking and cracking, and of frequent disassembly. Once the joint has been broken, there is always a possibility of a poor fit when it is reassembled.

The attachment or "making up" of this type of fitting is extremely simple. All that is necessary is to cut the tubing square at the end, slip the nut and the wedge cone on, in the order named, force the tubing solidly into the union so that it is in contact with the shoulder inside, and screw on the nut. Only experience can teach one just how tight to draw the nut. If it is too loose, the joint will leak; if it is too tight, the tubing is crushed more than is necessary. One method of checking the tightness of the joint is to assemble the fitting loosely, turn on the fuel so that the system is filled and then tighten the nut just enough to stop the leak.

Attaching Soldering Fittings - If joints are to be broken and reassembled frequently, this type of fitting is the most satisfactory, since neither the nut nor the union is in contact with the tubing. However, it must be remembered that soldering fittings cannot be used on aluminum or duralumin tubing, nor on any other material to which silver solder does not adhere.

To attach the fitting, the tubing is cut square and the nut and union tail slipped on. The tail is then brought flush with the end of the tubing and silver-soldered in place. The cone of the tail is placed in the conical seat of the union and the nut screwed on. This completes the assembly. Soft solder may be used in an emergency, care being taken to tin the tubing thoroughly at the point where it is in contact with the union tail. However, soft solder is not considered sufficiently dependable for aircraft work, and hence is not recommended. Instructions for silver-soldering have been given in a previous chapter.

Flexible Pipe Connections - Referring to the C.A.A. requirements at the beginning of this section, it will be noted that flexible connections of some type must be installed between the engine and the remainder of the structure. In other words, any fuel line which is directly connected to the engine must be equipped with a flexible joint to lessen the danger of crystallization due to engine vibration.

Flexible connections are of two general types: rubber or synthetic rubber hose, and specially constructed flexible tubing. Hose connections are cheaper and somewhat lighter, and hence are more common than the special tubing. The hose must be gas-resistant, as ordinary rubber deteriorates rapidly when exposed to gasoline or

oil. One of the most popular makes of "gas hose", as it is commonly called, is manufactured under the trade name of "Neoprene."

Fittings which are made to be used with hose are usually beaded at the unthreaded end, as illustrated in Fig. I of the preceding section. Also shown in this figure is a hose liner, which must be used on the inside of the piping when hose connections are made, to keep the fuel from coming in contact with the hose. Hose clamps have been discussed in a preceding chapter. When making hose connections in large tubing the ends are sometimes beaded with a special machine, or else a ring of wire is soldered near the end of the tubeto keep the hose from slipping off and to insure tightness of the joint. This practice is frequently omitted on tubing less than 1/2" in diameter.

Making a joint by means of a hose connection is a simple job. The ends of the tubing are cut absolutely square and the burrs removed. The hose, about 3" long, is slipped on one tube just past the end and the two hose clamps, loosened to the limit, put on the hose. The hose liner is inserted in one of the pieces of tubing and the other piece then pushed on the liner, so that the ends of the tubing should bear snugly against the shoulder. The hose is then pushed over the joint so that the ends of the tubing are located approximately in the center of the piece of hose. (Moistening the tubing slightly will make the hose slide more freely.) The hose clamps are located near the ends of the hose and tightened securely. This completes the joint.

One of the most popular types of flexible tubing is manufactured under the trade name of "Titeflex." This tubing is made of a strip of thin metal spirally wound into a convoluted tube which is protected on the outside by a braid of narrow strips of bronze. A longitudinal section of the tubing, with fitting attached, is shown in Fig. IX-A and an enlarged section of one convolution in B. This

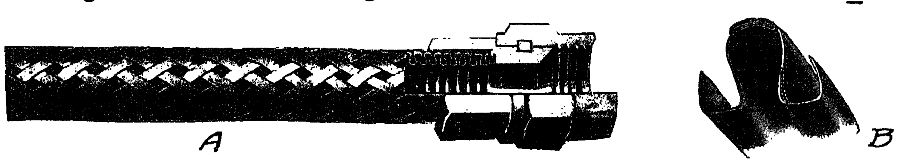


Fig. IX

tubing is very flexible and durable, and absolutely gas-tight. While it is possible for the mechanic to attach the fittings, it is better to order pieces of the proper length with fittings attached by the manufacturer. Since the tubing is of special construction, standard pipe fittings naturally cannot be used, fittings of a special type being supplied by the tubing manufacturer.

Installation of Fuel Lines - Careful work in the bending and fitting of fuel lines will be offset if the installation is not made properly. In this connection, there are several points which should be borne in mind. First, vibration of the tubing must be checked as much as possible. This is accomplished by supporting it wherever it passes near a substantial member. The support may be simply friction

tape wrapped around the tubing and the member. More satisfactory, however, is a small metal clamp which fits the tubing and which may be screwed or bolted to the structure. When such a clamp is used, the tubing should be protected by several wraps of friction tape, of vellumoid, or by a piece of split hose, at the point where the clamp is to be located. This same method of protection against chafing should be used wherever the tubing is in contact with any other part of the ship. Tape should be given one or two coats of shellac, especially if it is used as an attachment.

Second, the lines must be installed so that they can be removed without disassembling the airplane, since it is necessary to anneal them at regular intervals, preferably of about 100 hours of flying time. This precaution may seem so obvious as not to require special mention, but it often happens that a thoughtless mechanic, installing the lines before the plane is entirely assembled, fastens a clamp in some location which is entirely inaccessible after assembly. Another point to remember is that fittings which are screwed together should never be assembled with shellac, red lead, or any other gasket seal which hardens on the threads. If such materials are used, it may be found impossible to unscrew the fittings at some future date. On the other hand, it is desirable to coat the threads with some of the special compounds such as Parker's "Sealube" on aluminum fittings, or "Gaslube" on brass. If these are not available, a small quantity of ordinary grease may be used.

Third, the lines should be parallel whenever possible, both because they are easier to trace when so installed, and because the appearance of the job is greatly improved. Furthermore, a number of lines may be supported at a common point, by using a clamp designed to hold them all with one or two bolts or screws.

RELIEF AND BY-PASS VALVES

As a rule, relief and by-pass valves are not needed in a gravity fuel system. They are essential, however, in a system which uses an engine-driven fuel pump. The engine pump will invariably supply far more fuel than the engine can possibly use. This being the case, it is obvious that some means must be provided to dispose of the surplus fuel and to relieve the carburetor of excessive pressure. The relief valve, when installed in the line between the pump and the carburetor permits fuel to be pumped to the latter until a certain pressure, usually from six to ten lbs. per sq. in., has been built up, upon which the valve opens and allows the extra fuel to pass back into the tank or into the feed line between the tank and the pump. A simple relief valve is shown in Fig. I, and a diagrammatic cross-section of a relief valve, pump, and by-pass valve illustrated in Fig. II.

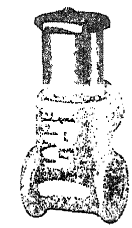


FIG I

The by-pass valve is necessary in systems employing an engine-driven pump in order that fuel may be pumped around the engine pump by means of the hand pump in case the engine pump breaks or for any other reason fails to function. It is also necessary to permit pressure to be built up on the carburetor for starting the engine. As previously explained, systems which use an engine pump must incorporate a hand pump for emergency and starting purpos-

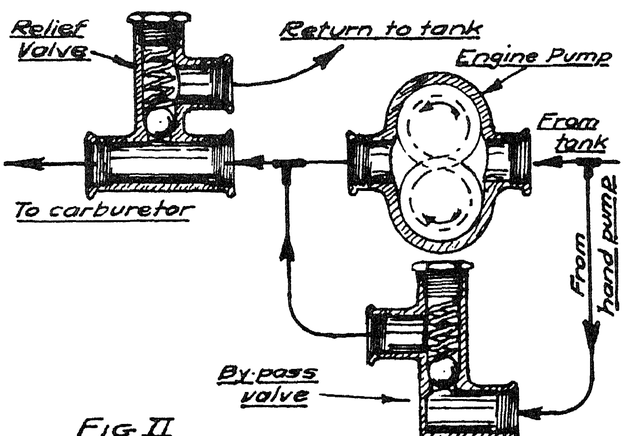


FIG II

The principle of operation of the by-pass valve is shown in the diagram in Fig. II. When the hand pump is not being operated, the ball remains on the seat, being held there by the spring. Since the ball fits the seat accurately, there is no danger of the suction of the engine pump being destroyed. As soon as the engine pump becomes inoperative, either due to failure, or because the engine is not running, the hand pump is used and the pressure of the fuel forces the ball up, allowing the fuel to pass around the engine pump. When either the hand pump or the engine pump is operating, the fuel must go through the pressure relief valve. As long as the pressure remains under the predetermined amount, the fuel passes directly by the valve. However, as soon as the pressure on the carburetor exceeds that for which the relief valve is set, the fuel forces the ball away from the seat, against the load of the spring. This allows the fuel to pass back to the tank as indicated and relieves the pressure at the carburetor. The pressure at which either the relief valve or the by-pass valve will open may be regulated by screwing

the cap down against the spring.

As pointed out above, the illustration in Fig. II is purely diagrammatic. In most cases the two valves are incorporated in one housing. This housing may carry only the valves, or it may be a part of either the hand pump or the engine pump. These latter combinations will be illustrated along with the various types of pumps. A combination of the two valves apart from a pump is shown in Fig. III. It will be noted that this unit provides connections for the primer and fuel pressure gage as well as for the other lines discussed above. The most common practice, however, is to incorporate the valves in the pump casting.

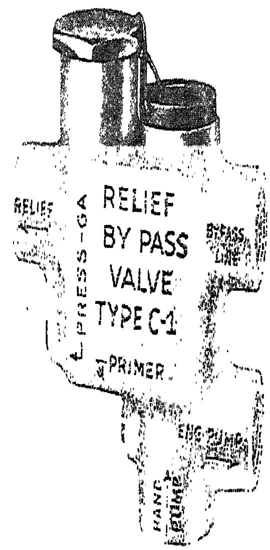


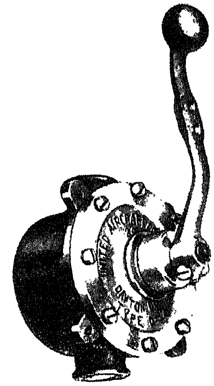
FIG. III

The pressure at which relief and by-pass valves operate is determined by strength of the spring and by the amount by which it is compressed. The operating pressure may be adjusted within reasonable limits by screwing down on the spring retaining nut to increase, or by backing off on the nut to decrease the pressure. This nut may be inside the housing immediately under the hexagonal cap, or, in some cases, the cap itself may be used as a means of adjustment. The cap is ordinarily provided with a small hole through which a piece of safety wire may be passed for locking it in the desired position. Needless to say, the cap should always be locked properly by passing wire through the hole and attaching it to some other portion of the fitting.

FUEL PUMPS

HAND OR "WOBBLE PUMPS"

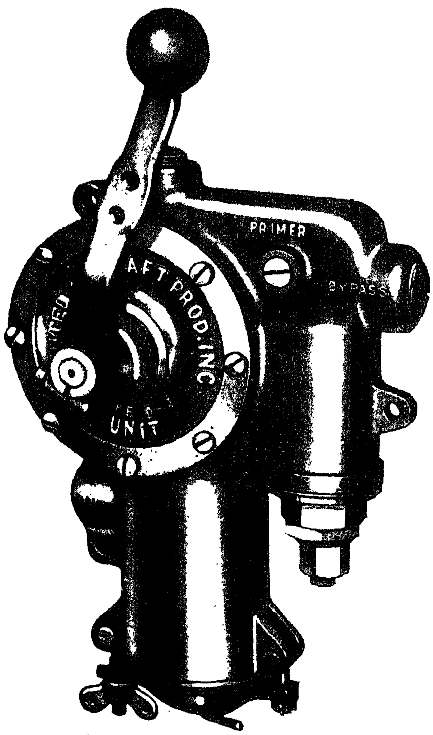
The simplest form of hand pump is illustrated in Fig. I. The hand pump is used, as previously explained, for starting or emergency purposes. The type shown in Fig. I incorporates no other accessory. The handle is provided with holes by means of which an extension rod may be attached for operating the pump at some distance from the pilot's seat. Such an arrangement is often desirable to cut down the length of the fuel lines. The pump is operated simply by moving the handle back and forth through approximately 100°, the movement giving rise to the name "wobble" pump.



Courtesy United Aircraft Products Co.

FIG. I

Fig. II shows a hand pump which, because of its additional accessories, is referred to as "a fuel unit." It will be noted that the housing includes a by-pass valve, a strainer (the cylindrical portion below the body of the pump), and a connection for the primer. Strainers will be discussed in more detail later.



Courtesy United Aircraft Products Co.

FIG. II

The hook-up of this type of fuel unit is illustrated in Fig. III. The fuel supply comes through a fuel cock (to be described later) which, in this case, provides for connections to three fuel tanks. The fuel enters the strainer and, under normal conditions, passes out at the top of the unit to the engine pump, and from there through a relief valve to the carburetor. The excess from the relief valve is led back to the fuel unit from which it again passes around to the pump. When starting the engine, or when the engine pump is for any reason not functioning, the fuel leaves the pump at the connection marked "BY-PASS" and passes directly to the carburetor. There are many styles of fuel units, each manufacturer incorporating his own features, but the general idea is the same in all of them. Some types include, in addition to the accessories shown in

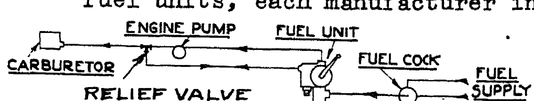


FIG. III FUEL SYSTEM DIAGRAM-SERIES FLOW

Fig. II, a relief valve, a connection for the pressure gage, and a shut-off cock. However, a knowledge of the principles of the fuel system will enable the mechanic to make the proper connections.

ENGINE-DRIVEN PUMPS

Gear Pumps - Engine-driven pumps are of two general types: gear pumps and vane pumps. The simplest type of gear pump is shown in Fig. IV. This pump does not include any of the relief or by-pass valves and consists simply of two gears, the rotation of which carries the liquid through the pump. It should be remembered that the path of the liquid is not between the gears but around the outside, as indicated in the diagram shown in Fig. V. Through ignorance of

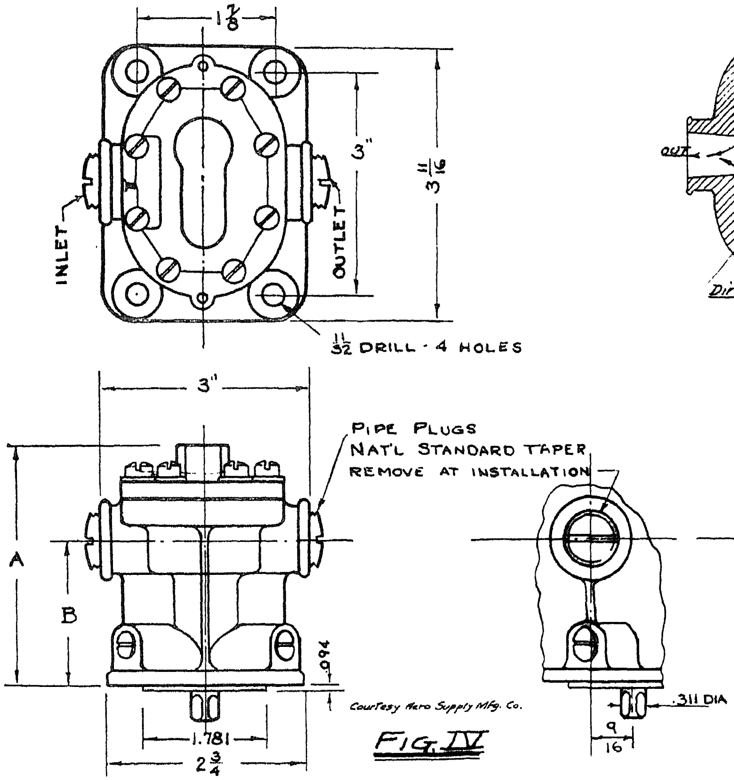
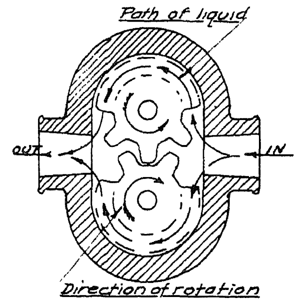


FIG. IV

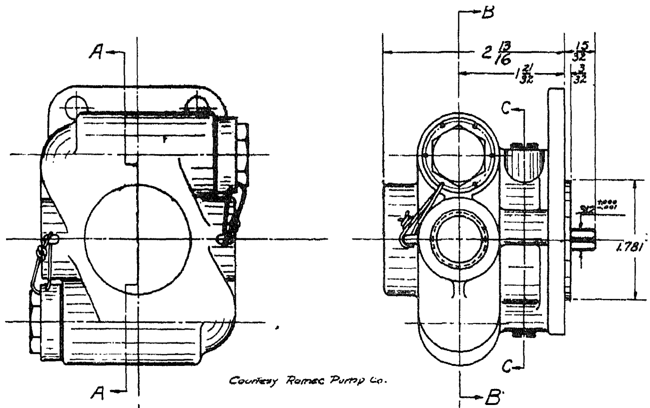


FI.

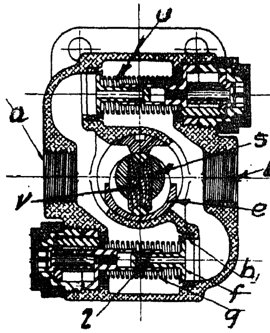
this fact, inexperienced mechanics sometimes connect such pumps backwards. Gear pumps can produce very high pressures, and for this reason are used almost universally for oil pumps as well as fuel pumps. They are not capable of any great amount of suction, particularly when they have not been primed by means of a hand pump. "Priming" in this instance simply means starting the liquid flowing through the pump. When the pump is full of liquid, the liquid itself tends to prevent air from leaking between or around the outside of the teeth and causing loss of suction. Engine-driven pumps are bolted directly to a pad provided on the engine crankcase, the square-ended shaft of the pump fitting a corresponding socket in another

shaft which is driven through gears by the engine crankshaft. The weight of these pumps is in the neighborhood of two pounds and the horsepower required to operate them is negligible.

Vane Pumps - The ROMEC solid-vane fuel pump, including by-pass and relief valves is shown in Fig. VI. This pump may be used in either direction, that is with the shaft, s, rotating either clockwise or counter-clockwise. However, when the direction of rotation is changed the function of the valves is also changed, the by-pass valve becoming the relief valve and vice versa. If the shaft, s, is assumed to rotate counter-clockwise, the fuel will enter the port, a, and leave by the port, b. Under these conditions, the lower valve, l, acts as the relief valve, and the upper valve, u, becomes the by-pass valve. When the pump is operating, the fuel entering at a is picked up by the vane, v, which is rotated in an eccentric housing, e, by the shaft, s. The shaft is slotted to receive the vane which is free to slide back and forth in this slot. The ends of the vane which bear on the housing are provided with rubbing strips, indicated by the small half-round sections at the ends of the vane. The fuel, having been picked up by the rotating vane, is held between the vane and the housing, almost as though the vane were a small paddle wheel or bucket, and is carried around the shaft to the port, b. Having reached this side, there is nowhere for the fuel to go except out of the port, which leads to the carburetor.



Courtesy Romec Pump Co.



SECTION BB

FIG. VI

However, as soon as pressure is built up on the carburetor, all of the fuel on the right-hand side of the pump, including that contained in the housing between the shaft and the port, b, is naturally under the same pressure. This pressure acts against the face, f, of the relief valve, pushing it back against the spring, g. This spring is set, as previously described, to produce the desired pressure on the carburetor. When that pressure is exceeded, the valve, f, moves away from the seat, h, and the fuel passes back to the left side of the pump housing and goes through the pump again. This eliminates the necessity for any overflow line back to the fuel tank.

If the pump is not running, as when starting the engine, or if the pump shaft is broken, the fuel is forced by the hand pump through the inlet, a. Having entered the pump housing, since the

shaft, s, is not rotating, the fuel obviously cannot pass around the shaft. Neither can it pass through the lower valve, l, as pressure on the left side of the pump tends to close this valve rather than open it. When the hand pump has produced a predetermined pressure, (which is lower than that required by the carburetor) the upper valve, u, is forced open and the fuel passes through this valve and out to the carburetor by means of the port, b.

This pump, just as the gear pump, is bolted directly to the engine crankcase and driven by the square end of the pump drive shaft. It requires little maintenance and if complete overhaul becomes necessary it should be returned to the factory.

The PESCO split-vane engine-driven fuel pump is illustrated in Fig. VII with cross-sectional views in Fig. VIII. This company manufactures a number of different styles of pumps, the one shown being, perhaps, of the

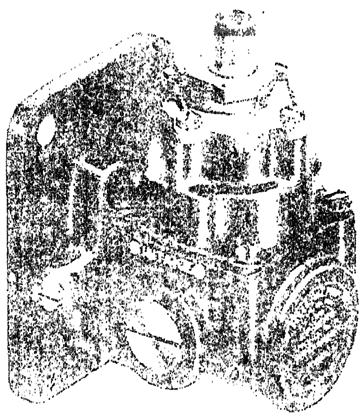
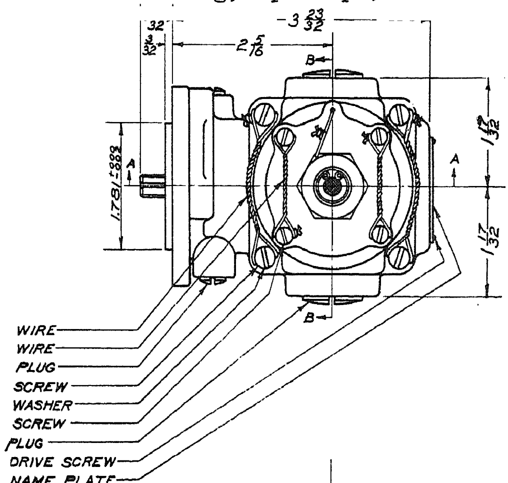
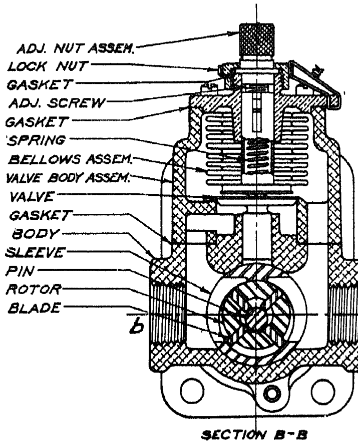


FIG. VII

Courtesy Pump Engineering Service Co.





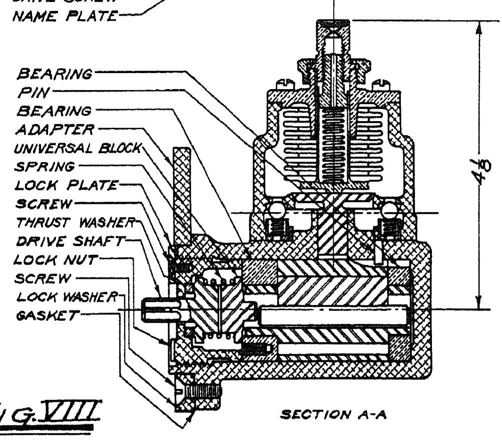


FIG. VIII

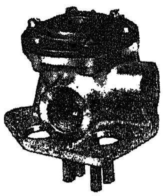
type most commonly used. The parts of the pump are labelled in Fig. VIII, a study of which will show that the general principles of operation are similar to those of the ROMEC pump just described. The relief valve is of the sylphon type, the sylphon consisting of a corrugated metal tube, referred to in Fig. VIII as the "Bellows Assembly." Due to the construction of the pump, it is impossible to show the relief and by-pass valves in the same view. The by-pass valve consists of a series of small ball check valves, two of which may be seen in the longitudinal section on the right of Fig. VIII. The relief and by-pass valve assembly may be removed from the pump as a unit and reversed so as to provide for the operation of the pump in either direction. It is essential that the side of the valve housing marked "INTAKE" be located on the intake side of the pump as otherwise the relief valve will not function properly. This pump is provided with two drain bosses, to the lower of which a 1/4" drain pipe should be connected and led to the outside of the airplane. At the top of the pump is a connection from which a line may be led to the blower section of supercharged engine. The pump is mounted on the engine in the same manner as those previously described.

In Fig. VIII the valve assembly is mounted for a clockwise rotation of the pump. The fuel enters the port at a and is carried around the rotor and out of the port, b. The rotor consists of a hollow shaft, slotted to receive the four vanes and driven by a flexible connection which terminates in a square end or attachment to the engine pump drive. The vanes are prevented from moving too far toward the center of the hollow rotor shaft by the pin shown in the drawing. When the fuel has passed through the pump, and pressure has been built up on the carburetor, the pressure on the pump housing (on the left side of the cross-section in Fig. VIII) forces the valve open against the sylphon and allows the fuel to pass to the right side and go through the pump again. When the pump is not operating, the hand pump forces the fuel in the port, a, and up into the chamber which carries the relief valve. As the hand pump builds up pressure, the relief valve is held more tightly closed but the ball check valves, shown in the longitudinal section in Fig. VIII, are forced open and the fuel is allowed to pass out through the port, b. The fuel pressure is adjusted by loosening the lock nut (See Fig. VIII) and turning the adjusting nut. Tightening, or turning this nut clockwise, increases the pressure; loosening it, decreases the pressure. The elasticity or springiness of the sylphon also tends to hold the valve shut, its effect varying with the pressure of the outside atmosphere, since air is admitted through the small hole in the center of the adjusting nut, (shown in section A-A, Fig. VIII). As in the case of the ROMEC pump, little maintenance is necessary and overhaul work should be done either by the factory or an authorized service station.

MISCELLANEOUS FUEL SYSTEM ACCESSORIES

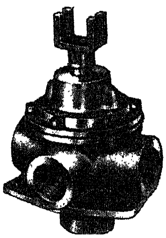
SHUT-OFF VALVES

When an airplane is provided with only one fuel tank, the shut-off valve may be extremely simple. However, the valve should be smooth and easy in operation yet at the same time absolutely gas-tight. For this reason fuel valves are usually provided with tapered, cork-surfaced cores, held against the seat by spring pressure.



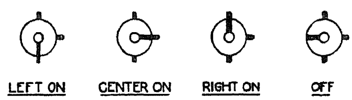
Type E

Where more than one tank is used, the shut-off valve must be so designed that any of the tanks can be used at the choice of the pilot. Two of the valves manufactured by the United Aircraft Products, Inc., are shown in Fig. I. The type E permits the use of two tanks. A diagram of the internal passages of this valve is shown to the right of the illustration. By referring to this diagram it may be seen that there are two "OFF" positions, and that either one or both of the tanks can be used.



Type G

FIG. I



Type G is intended for use where three tanks are installed. The center of the valve is hollow and a passage leads from this hollow center to the rim. This passage may be turned to any one of four positions, thus allowing the use of any one of the tanks or permits turning all of them off. The yokes shown provide for a universal joint between the shaft which turns the valve and the handle, as these valves are usually installed at some distance from the pilot's cockpit. The valves should be mounted to some solid portion of the structure by means of the flange. The operating handle, an example of which is shown in Fig. II, is ordinarily mounted on the instrument board or in some other location accessible to either pilot. The shaft from the control handle in the cockpit to the valve is ordinarily of steel tubing, approximately 1/2" in diameter, the size depending, of course, on the length.

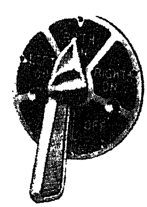


FIG. II

PRIMERS

There are several types of primers on the market, one of the most common being that manufactured by the Lunkenheimer Company. Primers may be adapted for use with one or more engines. Fig. I illustrates a Lunkenheimer primer for a three-engine installation. The primer is usually installed on the instrument board, simply by boring a hole through the board large enough to take the barrel of the primer and another to fit the shaft for the shut-off cock. The barrel of the primer is threaded so that a nut may be tightened down against the instrument board from each side, thus holding the primer firmly in place.

The primer is nothing but a simple hand pump. When the plunger is drawn out, fuel is sucked into the barrel through a check or one-way valve. When the plunger is pushed in, this valve closes and the

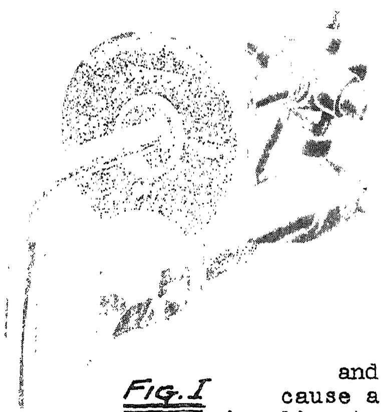


Fig. I

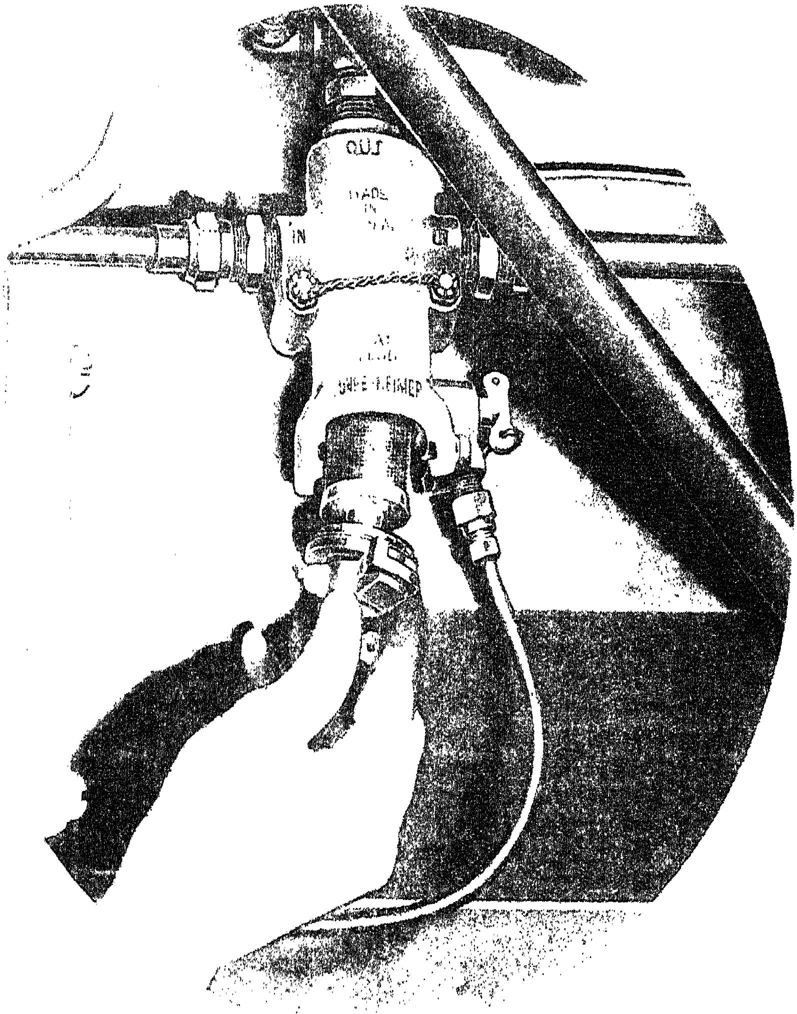
fuel is forced out through another check valve to the priming connection on the engine. The plunger of the primer is provided with a small projecting pin which fits a notch in the packing nut. The plunger is pushed home with the pin lined up with the notch. After the pin enters the notch, the plunger is rotated half a turn and is then locked against opening accidentally. However, vibration sometimes causes the plunger to work around until the pin lines up with the notch and the plunger springs out. This may cause a leakage of fuel through the priming line to the engine, producing a rich mixture which may cause engine failure. For this reason, a shut-off is supplied, which should always be turned to the "Off" position when the engine is running.

Primer lines are usually of copper 1/8" in diameter. The feed line is led from a connection on the fuel system. This connection may be made to the fuel line proper, at any point where the fuel is under pressure, or it may be embodied in the hand pump or strainer, as previously described. The outlet line from the primer is led to the priming connection on the engine. Some engines provide a connection in the rear of the blower section, while others have connections on several of the cylinders. The location of this connection on any particular engine can be determined only by an examination of the engine in question.

STRAINERS

Strainers of adequate capacity must be located between the fuel tanks and the engine, and should be in some location which renders them accessible for inspection and cleaning. Strainers are frequently provided with a drain leading outside the cowling, which may be operated by the pilot and by means of which any accumulated dirt or water may be drained while in flight without disassembling the strainer. The strainer consists of a cast aluminum alloy housing in which is a screen of wire gauze. The fuel ordinarily enters the strainer near the bottom or half way up the side and leaves it at the top, after passing through the gauze. A typical strainer installation is illustrated in Fig. I, which also shows the method of removing the gauze screen for cleaning. The drain is also indicated in this illustration. In this case the drain is not operated from the pilot's cockpit. Needless to say, the drain and the nut which holds the gauze screen in place should be carefully safetied, as if either should become loose, the fuel might not reach the engine and a forced landing might result.

Strainers should be cleaned with gasoline and compressed air, or with a soft bristle brush; never with a wire brush. The sediment should be inspected for foreign matter which might indicate



Courtesy Lunkenheimer Co.

deterioration somewhere in the fuel system. All gaskets should be carefully inspected before replacing them, and after the strainer has been reassembled and safetied, the fuel should be turned on to see that there are no leaks. If the system is of the pressure type, the hand pump should be operated so as to put pressure on the strainer and connections.

CHAPTER 8
LUBRICATION

With respect to the lubrication system, engines may be divided, as previously mentioned, into two general types, known respectively as the wet sump and the dry sump. In the wet sump engine, the oil is carried in the crankcase and no external tank is necessary. All automobile engines are of this type. In dry sump engines the oil supply is carried in a separate tank, and is returned from the sump to the tank by a scavenger pump as fast as it passes through the engine. Practically all modern aircraft engines are of the dry sump type. It is obvious that no appreciable amount of oil could be carried in the crankcase of a radial engine without flooding the cylinders, and in the case of an in-line engine it is desirable to keep the crankcase free of oil which would run into the cylinders in the case of inverted flight or other acrobatic maneuvers. Apart from the matter of oil storage, the lubrication principles of both the wet and the dry sump engine are the same and since the wet sump is so rare in aircraft use it will not be discussed further.

THE EXTERNAL OIL SYSTEM

Civil Aeronautics Authority Requirements. The Civil Aeronautics Authority makes the following requirements for lubrication systems:

"Each engine shall have an independent oil supply. The oil capacity of the system shall be at least 1 gallon for every 16 gallons of fuel for single-engine aircraft and 1 to 20 for multi-engine aircraft but shall not be less than the minimum specified by the engine manufacturer for safe operation of the engine. A special ruling concerning capacity will be made by the Secretary when oil may be transferred between engines in flight or when a suitable reserve is provided. The suitability of the lubrication system shall be demonstrated in flight tests in which engine temperature measurements are obtained. The system shall provide the engine with an ample quantity of oil at a temperature suitable for satisfactory engine operation.

"Oil tanks shall be suitably vented and shall be provided with an expansion space which cannot be inadvertently filled with oil. Such expansion space shall be at least 10 per cent of the total tank volume, except that it shall in no case be less than one-half gallon.

"Oil tanks shall be capable of withstanding an internal test pressure of 5 pounds per square inch without failure or leakage. Tanks shall be so designed and the rivets or welds so located as to resist vibration failures and leakage.

"A suitable means shall be provided to determine the amount of oil in the system during the filling operation.

"Oil piping shall have an inside diameter not less than the inside diameter of the engine inlet or outlet and shall have no splices between connections. Connections in the oil system shall be of a type satisfactory to the Secretary.

"One or more accessible drains shall be provided at the lowest

point on the lubricating systems to drain completely all parts of each system when the airplane is in its normal position on level ground. Such drains shall discharge clear of all parts of the airplane and shall be equipped with suitable safety locks to prevent accidental opening.

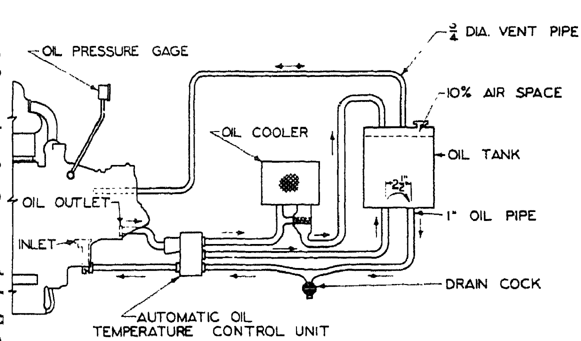
"A suitable means shall be provided for measuring the oil temperature at the engine inlet.

"All filler openings in the oil system shall be plainly marked with the capacity and the word 'oil'."

A few words of explanation with respect to these requirements may be desired. As regards the vents, it is usually customary to lead the vent line back to the engine crankcase so that if there is any tendency for the oil to foam out of the vent, it will not be wasted. Most engines provide a connection on the crankcase for such a vent. Since the crankcase is vented through the breather to the outside atmosphere, air can readily pass through the vent line to the tank. The reason for the expansion space is that oil expands when (it is) heated and if the tank were entirely full of cold oil, a large quantity would be forced out of the vent after the engine warmed up. If the vent led directly to the outside air, this oil would be lost, whereas if the vent line were connected to the crankcase, the engine would be flooded with oil, quite possibly to the extent of causing engine failure, due to fouled spark plugs.

The gage referred to may be nothing more than a rod or strip of metal attached to the filler cap and marked or stamped to indicate the amount of oil in the system. This type of gage is probably the most satisfactory.

Due to the large size of oil lines and the desirability of lessening vibration, the connections are usually made with special fuel or oil hose. The method of making the connection is the same as that described for hose connections in the chapter on fuel systems. The drains should be as large as practicable, for oil is extremely viscous, particularly when cold, and unless a large opening is provided, a great deal of time would be required to drain the system.



Courtesy Pratt & Whitney Aircraft

FIG. I

Oil System Diagram - A typical oil system, as recommended by the Pratt & Whitney Company, for use with their engines is shown in Fig. I. It will be noted that this system incorporates an oil cooler and a

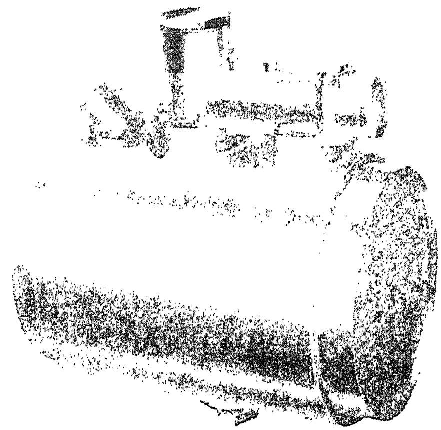
separate automatic oil temperature control unit. In many installations these two items are combined. In the system illustrated, the oil is led from a tank directly through the temperature control to the inlet connection on the engine. The return line also passes through the temperature control but its course from there on depends upon the temperature of the oil. When the oil is cold, a thermostatic valve in the control unit causes the oil to pass directly back to the tank to a point very near the feed line coming from the tank. This means that a comparatively small amount of oil is in circulation, and hence tends to warm-up quickly. As soon as the temperature reaches the desired point, which is in the neighborhood of 140° F. - 167° F., the oil is directed to the oil cooler, from which it is led to the upper part of the oil tank. The oil cooler is simply a radiator, such as the radiator used on automobiles or on liquid-cooled aircraft engines. It will be noted that in this installation, the tank is vented through the crankcase and that the required amount of expansion space is mentioned on the drawing. The oil pressure gage, indicated in the diagram, is mounted on the instrument board, or at some point easily visible to the pilot. An oil temperature gage is also necessary and is usually installed at or near the engine outlet so that the outlet oil temperature is indicated. Some manufacturers recommend installing a temperature gage on the inlet side of the engine, while in still other cases a gage is connected at both the inlet and the outlet so as to give even more accurate indication of how the lubrication system is functioning and whether or not the engine is becoming unduly hot.

Oil Tanks - Everything that has been said in connection with the construction and repair of fuel tanks applies also to oil tanks. The chief differences between fuel and oil tanks are that the oil tanks have a smaller capacity, must be made much stronger and can be repaired with less hazard, due to the fact that a torch can be used on them with little danger of blowing up the tank. They are mounted in the same general manner as fuel tanks, but are usually on the engine side of the firewall, so as to eliminate extensive piping and because oil is not explosive.

Oil Lines - Oil lines are made from the same materials and in the same general manner as fuel lines. The chief difference is that oil lines are always much larger in diameter than the fuel lines of a given engine and hose connections are usually employed instead of fittings. The rules for making oil lines are the same as for making fuel lines. The same methods of fabrication and the same sort of bending devices are used. Oil lines are ordinarily marked near the ends with bands of yellow paint, though before applying such marking it should be determined whether or not the practice and color is customary with the owner of the aircraft.

Oil Temperature Regulators - In place of the temperature control unit illustrated in Fig. I, a special valve is often incorporated in the oil cooler and the combination of cooler and valve is referred to as an all-temperature regulator. Fig. II shows an oil-temperature regulator manufactured by the United Aircraft Products, Inc., and incorporating a thermostatic relief valve. When the oil is cold it does not pass through the radiating part of the regulator, but is led directly back to the oil tank. As the oil warms up, the

thermostat opens the valve and permits the oil to pass through the cooling core. Another type, made by the same company, uses a viscosity valve instead of a thermostat. Since cold oil is much more viscous than hot oil, this type of valve provides an excellent means for controlling the temperature by means of the viscosity. A third type uses a spring-loaded relief valve. Cold oil is naturally much "thicker" than hot oil and hence requires more pressure to be forced through small openings. By using a pressure relief valve in the temperature regulator, the cold oil is by-passed around the cooling unit until its temperature has been raised to the desired degree.



Courtesy United Aircraft Products, Inc.

FIG. II

There is still another type of oil temperature regulator used with liquid-cooled engines which operate at comparatively low coolant temperatures. In this regulator, the engine coolant flows through the core in place of air. This has the double effect of raising the temperature of the oil to that of the coolant and thus warming up the engine more quickly, while at the same time holding the oil temperature down to that of the cooling liquid. On chemically-cooled engines in which the temperature of the coolant is above the boiling point of water, this type of regulator is not suitable.

On many of the smaller engines the oil cooler consists simply of a small radiator without any of the by-pass or regulating valves previously discussed. The radiator is usually mounted in such a manner that the flow of air through it can be controlled by some type of shutter. In modern aircraft the radiator is ordinarily inside of the engine cowling with an air passage, the opening of which can be controlled from the cockpit, leading from the outside air through the radiator and back to the outside again.

External Oil Strainers - In addition to the strainers which are inside of the engine, some engines, among which are the Wright and the Jacobs, provide an external strainer on the return line. This strainer is of the wire gauze type, somewhat similar to the fuel strainer previously discussed, but with a much larger screen area. It is put on the return line because the temperature of the oil is raised after it has passed through the engine and consequently its viscosity has been decreased so that it will flow more readily through the screen. If the strainer were placed on the intake side, the cold oil would not flow through in quantities sufficient to lubricate the engine and furthermore would have only the suction of the pump to draw it through the screen. Gear pumps, as previously mentioned, are not particularly effective in suction and hence if the strainer were installed on the intake side, the engine would un-

doubtedly be damaged, due to insufficient lubrication when it began running. By placing the strainer on the outlet side, not only is the oil much thinner, but it is being driven by a gear pump which is entirely satisfactory for producing pressure. Strainers of this type are usually provided with a pressure relief valve built into the screen, so that if the oil is too thick to pass through the wire gauze, the valve will be forced open before a dangerous pressure has been built up. The screen in these strainers should be removed and thoroughly washed with a gasoline spray whenever the oil is changed; and at the same time the housing or bowl should be flushed out with gasoline and wiped clean with a cloth.

Fig. III shows a Cuno Oil Filter which is extremely effective. This strainer is self-cleaning and the model illustrated has been adapted by the Wright Aeronautical Corporation to be operated by the engine instead of manually. The construction of the filter embodies a series of wheel-shaped discs assembled on a rotatable shaft and separated from each other by spacers having a thickness of .0035". These discs are surrounded by a housing which is large enough for an appreciable space to be left between the walls of the housing and the edges of the discs. The oil enters the space between the housing and the disc and is forced by the engine pump between the discs, and into the passages made by the "spokes" of the discs. From this passage it is conducted to the outside oil lines.

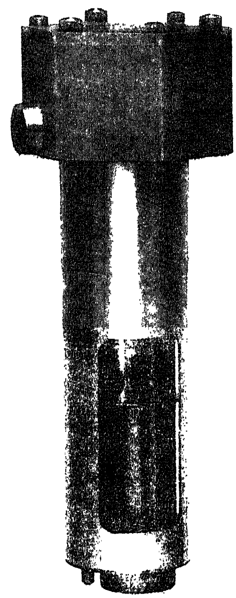


FIG. III

The closeness with which the discs are assembled to each other prevents foreign matter from passing between them and any lint, carbon, or gum, is retained by the edges of the disc so that the oil is clean when it leaves the filter. This filter also incorporates a series of blades, arranged very much like the blades of a comb, which pass between the discs when the shaft carrying them is rotated. These blades scrape off the accumulated residue on the edges of the discs and allow it to fall into a sediment pan at the bottom of the filter. The entire core and the pan of the filter may be removed periodically and cleaned with gasoline. In early models of this device, the shaft was rotated by hand, but later types incorporate an oil-driven motor which turns the filter core continuously during engine operation. This motor is entirely self-contained and has no external controls or pipe lines. By this device the filter is constantly cleaning itself. The oil motor turns the core at a very slow rate but even if it should fail to turn at all, the filter still functions and insures that clean oil will be supplied for many hours of operation or until repairs can be made.

<u>General Precautions on Oil Systems</u> - When installing oil lines, they must be braced against vibration and wear by attaching them to

portions of the structure at convenient points. They must also be protected against chafing at such locations by wrapping them with friction tape, shellacked in place, or by some other protective material. This protective wrapping should be applied wherever a line touches any support or other part of the airplane.

In cold weather the oil tends to congeal in the line, which impedes its rate of flow and furthermore may reduce its temperature to an undesirable point.

To prevent this chilling, the line should be lagged in some manner. One satisfactory method of lagging is to cover the tubing with flexible asbestos sheet, held in place by friction tape wrapped around it in such a manner that the turns overlap, forming a continuous coating of tape. The tape is then painted with shellac as usual.

If the oil tank is so designed that the oil returning from the engine falls more than 10" after entering the tank, considerable foaming will be produced. The oil may be so permeated by air as the result of this foaming that the oil pressure will drop. The trouble can be avoided by designing the connections for the tank so that the return oil pipe is slightly below the level of the oil in the tank. However, if this is done, it will be necessary to drill a small hole in the inlet pipe just after it enters the tank to act as a siphon breaker. Another method of eliminating foaming is to arrange for the return oil to be discharged into a sloping trough, down which it will run smoothly into the remainder of the oil.

Oil tanks should be installed so that they are not appreciably lower than the pump, since, as previously mentioned, gear pumps are not satisfactory for suction. On the other hand, if the oil tank is too high, so that an appreciable pressure head is produced on the pump, there is likely to be considerable leakage of oil through the pump into the engine. This results in a waste of oil and furthermore is likely to flood the lower cylinders, necessitating the removal of the spark plugs before starting.

The oil pressure line should be connected to the designated fitting on the engine at one end and at the other end to the pressure gage on the instrument board. On some installations, particularly where the engines are mounted in the wing, the pressure gage line is necessarily of considerable length. As a result, the oil in this line may become congealed in extremely cold weather, causing the oil pressure gage to give an incorrect reading or even fail to register at all. The Wright Company recommends that the pressure gage line be filled with an SAE 10-W oil of good quality for cold weather operation. After the oil pressure gage line is filled with this light oil, all connections should be kept tight to prevent the oil from running out.

INTERNAL OIL SYSTEMS

Due to the many devious passages through which the oil passes in a large radial engine, it is almost impossible to indicate the entire circulating system in one scale drawing. Furthermore, the

system in each engine is different, although the same principles are employed in all. Fig. I is a semi-diagrammatic drawing of the internal oil system in a modern radial. The crankshaft and crankcase are

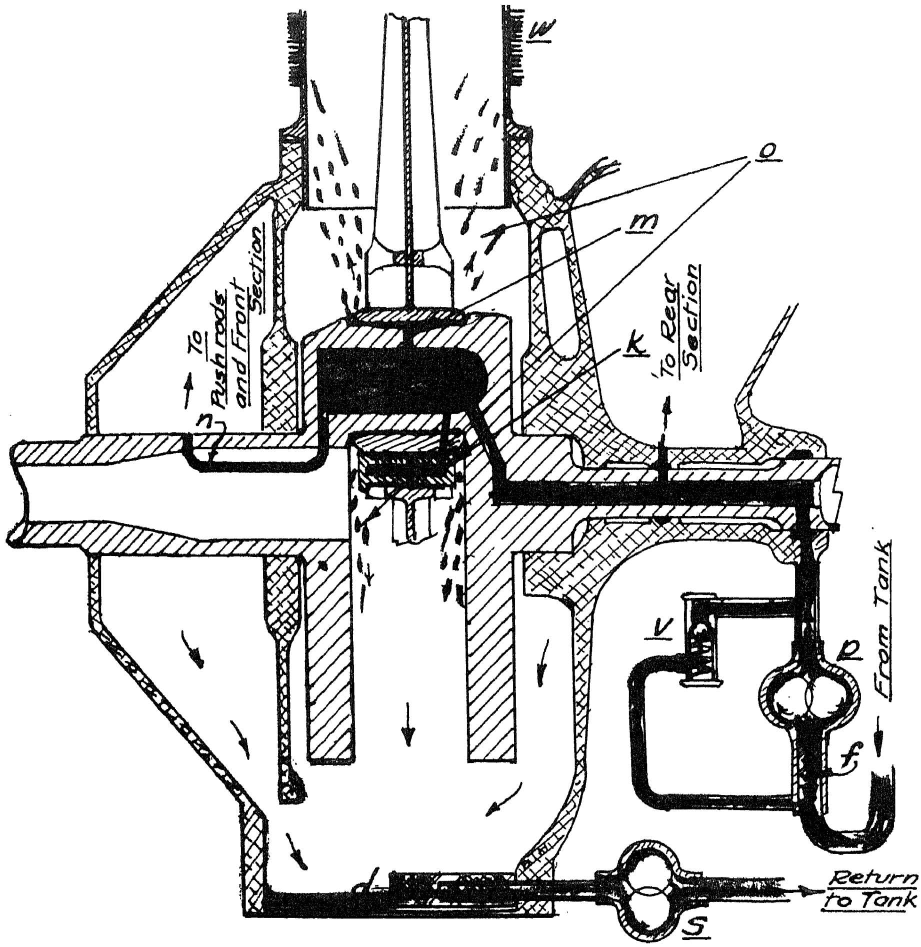


FIG. I

approximately to scale, but many of the parts are omitted for the sake of simplicity. The pumps and relief valve are purely diagrammatic and are not in their actual relationship, as regards position, either with the engine or with each other. The pressure and scavenger pumps are usually driven by the same shaft and furthermore there are frequently two or more of each. However, a study of the illustration with the accompanying explanation should provide an understanding of the principles employed in all aircraft engines. The oil,

indicated by the black areas, is drawn from a tank, usually through a coarse meshed finger-strainer, f, by the pressure pump, p. This is a gear pump, identical in operation with the gear fuel pump illustrated in the preceding chapter, though the gears of the oil pump are usually smaller than those used in the fuel pump. The oil is discharged from the pressure pump into a passage which leads, eventually, to the hollow interior of the crankshaft, c. The oil is usually introduced into the crankshaft at the rear bearing. The bearing is provided with an annulus, or groove, entirely around the interior of the bearing. At the point where this groove surrounds the crankshaft, holes are drilled from the outside of the crankshaft to its hollow interior. The annulus is, of course, kept continuously full of oil by the pump and since this oil is under pressure it is forced througn the holes drilled in the crankshaft into the interior of the shaft. Other passages may lead from this annulus to the various accessory drives, supercharger gearing, and other points that require pressure lubrication. The oil can escape from the crankshaft only by oozing out between the bearing surfaces. However, the pump is capable of building up an extremely high pressure and also of supplying a great deal more oil than the engine needs. If too much oil is supplied, the excess will work up into the combustion chamber and foul the spark plugs, as well as producing an undue amount of carbon. Accordingly, the pressure of the oil must be maintained at a definite figure. This pressure is determined by the relief valve, v, which is simply a spring-loaded ball or plate, similar in design to the other pressure relief valves previously discussed under "Fuel Systems." This valve is ordinarily built into the pump housing or into the crankcase very near the pump and may be adjusted by increasing or decreasing the tension on the spring. This adjustment is obtained in some engines by means of a screw and in others by means of washers inserted between the spring and the retaining nut. When this valve is set to open at a pressure of 60 lbs./sq.in., for example, it is obvious that no greater pressure can be produced through the inside of the crankshaft or anywhere else in the system. The excess oil, which passes through the relief valve, is led back into the passage connecting the tank feed line and the pump, and is thus carried through the pump and back into the system again.

The main connecting rod bearing is lubricated by means of holes drilled from the outside of the crank pin to the interior, as shown at m. The oil is forced through these holes and between the bearing surfaces. It is then thrown off by the crankshaft in fine drops, or spray, as indicated at o. Other holes through the crank pin line up with holes in the master rod bearing which lead to the knuckle pins. The knuckle pins thus are provided with fresh lubrication and the excess oil that works out around the knuckle pin bearings is also thrown on the cylinder wall. From the crank pin a passage leads to the forward portion of the crankshaft, as indicated at n. Oil from this passage is used to lubricate moving parts in the nose section, and by means of an annulus in one of the front bearings may be led to the rocker arms and to the hydro-propeller control. The oil which has been thrown on the cylinder walls and which is forced out of the bearings in the nose section, runs down the walls of the crankcase or falls, as indicated by the arrows, and eventually collects in the pump. Here it passes through a sump strainer, d, and is picked up by the scavenger pump, s, which returns it to the tank. This return oil

cannot, of course, accumulate in the lower cylinders since the skirts of the cylinders project for an appreciable distance into and past the interior surface of the crankcase.

Maintenance of Internal Oil System - When the engine oil is changed and at the regular periodic checks all the strainers in the system should be removed and thoroughly cleaned with a gasoline spray. The location of these strainers varies, of course, with individual engines and must be obtained from the instruction book. Also during the periodic engine checks it is well to remove the relief valve and clean it, particularly if the drained oil seems unusually dirty. A small particle of dirt caught under the ball or plate of the relief valve will cause a serious drop or complete loss of oil pressure. When this occurs, cleaning the relief valve will remedy the trouble. There is little further maintenance that can be done on the interior lubrication system. When the engine is overhauled, all of the numerous oil passages should be blown out thoroughly with compressed air and gasoline, but this is impossible when the engine is assembled.

It should be emphasized that successful operation of an engine depends largely upon satisfactory lubrication and only such oils as are recommended by the manufacturer should be used. In many cases, the grade of oil is varied according to temperature. Manufacturers' recommendations in this respect should also be carefully carried out. Needless to say, the utmost care should be used in keeping the oil and the oil tanks clean and free from any grit or other foreign matter.

CHAPTER 9
ELEMENTARY ELECTRICITY

Originally the use of electricity in connection with power plants was limited mainly to the ignition system. This was due to the excessive weight of the equipment necessary to produce or furnish electricity in large quantities. With the present larger and more efficient airplanes it is possible to carry the additional weight necessary to supply this electricity, consequently its use has increased in proportion to the growth of the airplane itself. This is especially true of the larger ships which utilize the medium of electricity to control engines, to register the performance of these engines on instruments in the cockpit, to power controllable pitch propellers, etc.

While it is not possible to give a complete course in electricity in this book, some of the essential basic principles will be presented to serve as a review for those who have studied the subject. If the mechanic has never studied electricity it is suggested that he secure a good vocational book on the subject and thoroughly familiarize himself with its contents. In addition to textbooks there are some excellent correspondence courses which cover the subject thoroughly. Electricity is a power, force, or agent that has not been definitely defined or described. There is still little known about what electricity is, however much is known about its properties and manifestations or actions. So without delving too deeply into why electricity acts as it does, we can proceed with the presentation of the laws and principles governing its actions.

TYPES OF ELECTRICITY

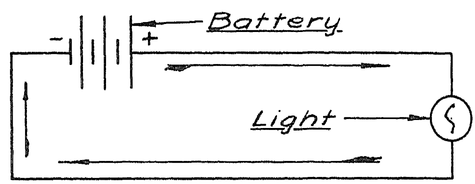
There are two types of electricity, static and dynamic - (not actually two different kinds, but rather different "conditions" of electricity).

Static Electricity - This is electricity at rest or an accumulation of electricity, an example of which is found in natural phenomena such as the static charge of electricity which accumulates in the earth or in the clouds. This accumulation often manifests itself by an electrical discharge which we call lightning. Static electricity may also be produced by rubbing a glass rod with a piece of silk. Under certain conditions it is possible to generate or produce static electricity in the body by shuffling the feet over a thick rug. If the finger is then held near some metal object connected with the earth, such as a radiator or water faucet, the static electricity thus produced will manifest itself by a visible spark from the finger to the metal contact. This type of electricity cannot easily be harnessed or controlled, therefore it is of no value in electrical equipment or installations in the airplane.

Dynamic electricity is electricity in motion, often referred to as "current electricity." This type of electricity is easily generated, stored and controlled and for that reason is used exclusively in electrical installation and equipment. The ensuing discussion of electricity will deal only with dynamic electricity.

Electromotive Force - Electricity has the power to move or flow from an object of high potential to an object of lower potential. By potential we mean simply the electrical condition of a body. To provide a standard for comparison, the earth is assumed to be an infinite reservoir of electricity having electrical potential of zero. Any object which has a higher potential than the earth is said to have a positive (+) charge. Likewise any object with a lower potential than the earth is said to have a negative (-) charge. As electricity flows from the high potential to the low potential, it is said to flow from a positive charge to a negative charge, or from + to -. The greater the difference between the potentials of the bodies the greater will be the pressure or force causing the electricity to flow from one to the other. The force or pressure which causes the electricity to move is called electromotive force (abbreviated e.m.f. or E.)

Voltage - A volt is the unit by which electromotive force is measured. Thus the more volts in an electrical path, the more pressure there is tending to make the electricity flow. The number of volts in this path or circuit is called its voltage and is measured by an instrument called a volt meter.

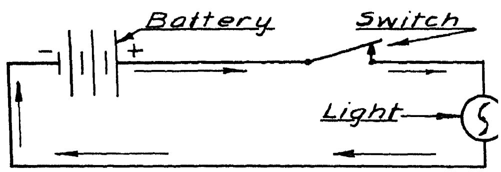


Direction of flow in circuit
FIG. I

Circuits - The electrical path from a positive to a negative charge is called a circuit, illustrated in Fig. I

The battery in this illustration is an object which contains two bodies, one having a positive charge and the other a negative charge. (See Primary Batteries). The electricity flows or moves through the wire conductor from the positive side of the battery to the negative side. A conductor is any material through which electricity will flow readily. The voltage of this circuit is the difference in electrical potential between the positive and negative sides of the battery. This is referred to as the circuit voltage, or battery voltage.

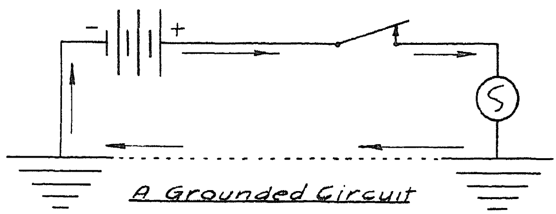
A circuit diagram is the representation of the path of an electrical current from a point through one or more conductors and back to that point. Circuit diagrams usually use conventional symbols or signs to represent various electrical devices. Some of the most common symbols are shown in the following pages. Fig. II is a circuit diagram showing a closed circuit. If the circuit is broken by opening the switch the



A Closed Circuit
FIG. II

electricity cannot complete its path from positive to negative and the circuit is therefore called an open circuit. Naturally the light will burn only when the circuit is completed by closing the switch.

Another type of circuit is the grounded circuit, shown in Fig. III. In this type of circuit the wire conductor does not form a continuous path for the circuit, but terminates in a common conductor such as the earth or, in the case of an automobile or airplane, the metal framework. In grounded circuit diagrams the path of the current through the ground may be designated by a dotted line, though this is not customary.



A Grounded Circuit

FIG. III

Amperage - As previously explained, the force with which electricity moves through a circuit is measured in volts. The amount of electricity or current which is moved through the circuit is measured in amperes by an instrument called an ammeter. Amperage or current is designated by the capital letter I.

Resistance - In any electrical circuit there is a certain amount of resistance or opposition offered to the current passing through. The unit of measure for this resistance is called an ohm, and is designated by the capital letter R.

RELATIONSHIP BETWEEN VOLTS, AMPERES AND OHMS

There is a definite relationship between the electromotive force, the current, and the resistance in a circuit. This relationship becomes more apparent if it is compared to a liquid such as water. The voltage of a circuit may be thought of as the pressure or head of water, the amperage may be considered as the amount of water, and the resistance as the diameter of a pipe through which the water flows. Considerable pressure is needed to force a large amount of water through a pipe of small diameter. Likewise, it is necessary to have a high voltage to force a large amperage through a circuit that has a high resistance. It requires only a small pressure to send a small amount of water through a large pipe. Similarly, only a small voltage is needed to force a small amperage through a circuit having a low resistance. This relationship between voltage, amperage and resistance is expressed in the Ohm's law, which may be interpreted as follows:

Ohm's Law - The strength of a continuous current of electricity in a circuit is directly proportional to the electromotive force, and is inversely proportional to the resistance of the circuit. It therefore follows that the strength of the current in the circuit is equal to the quotient procured by dividing the e.m.f. by the resistance. Reducing the law to a formula, it may be written thus:

$$\text{Current (Amperes)} = \frac{\text{Electromotive force (volts)}}{\text{Resistance (ohms)}} \quad \text{or } I = \frac{E}{R}$$

A practical application of the formula is shown in the following example. To find the strength of the current in a circuit which has an electromotive force of twelve volts and a total resistance of 24 ohms, divide the 12 (volts) by the 24 (ohms) which gives a quotient of 1/2 or .5, the strength of the current in amperes. This may be expressed in a written form:

$$I = \frac{E}{R} \text{ or } I = \frac{12}{24} \text{ or } I = 1/2 \text{ (ampere)}$$

If the strength of a current and the e.m.f. is known it is possible to find the resistance in the circuit by solving the same formula. In a circuit having an e.m.f. of 12 volts and a current of 2 amperes, the resistance would be determined as follows:

$$I = \frac{E}{R}, \text{ transposing, } R = \frac{E}{I} \text{ or } R = \frac{12}{2} \text{ or } R = 6 \text{ (ohms)}$$

Similarly the e.m.f. in a circuit may be determined if the current and resistance are known. If a circuit has a resistance of 12 ohms and a current of 1/2 ampere, the e.m.f. is found by expressing the formula in the value of E.

$$I = \frac{E}{R}, \text{ transposing, } E = I \times R, \text{ or } E = 1/2 \times 12, \text{ or } E = 6 \text{ (volts)}$$

ELECTRICAL TERMS

A.C. - This is the abbreviation for alternating current. A.C. current flows in one direction through the entire circuit, and then reverses and flows in the opposite direction, back through the circuit. It changes its direction many times in one minute, this rate of change being called frequency.

AMPERE - The unit of current flow, or the amount of electricity that is flowing through a circuit.

AMPERAGE - The number of amperes in a circuit.

ANODE - The path of the electric current from the positive to the negative pole. The positive pole is often referred to as the anode.

BATTERY - A source of electricity consisting of two or more cells.

CATHODE - The negative pole.

CELL - A single unit for the storage of electricity.

CIRCUIT - The path of electric current. A closed circuit is a path of conductors so arranged that the electricity may flow from its source through the circuit and back to its source. When a switch in the circuit is opened, the electricity cannot complete this cycle. This is called an open circuit.

CIRCUIT, SHORT - A more direct path of current from the positive to the negative eliminating all, or a portion of the original resistance.

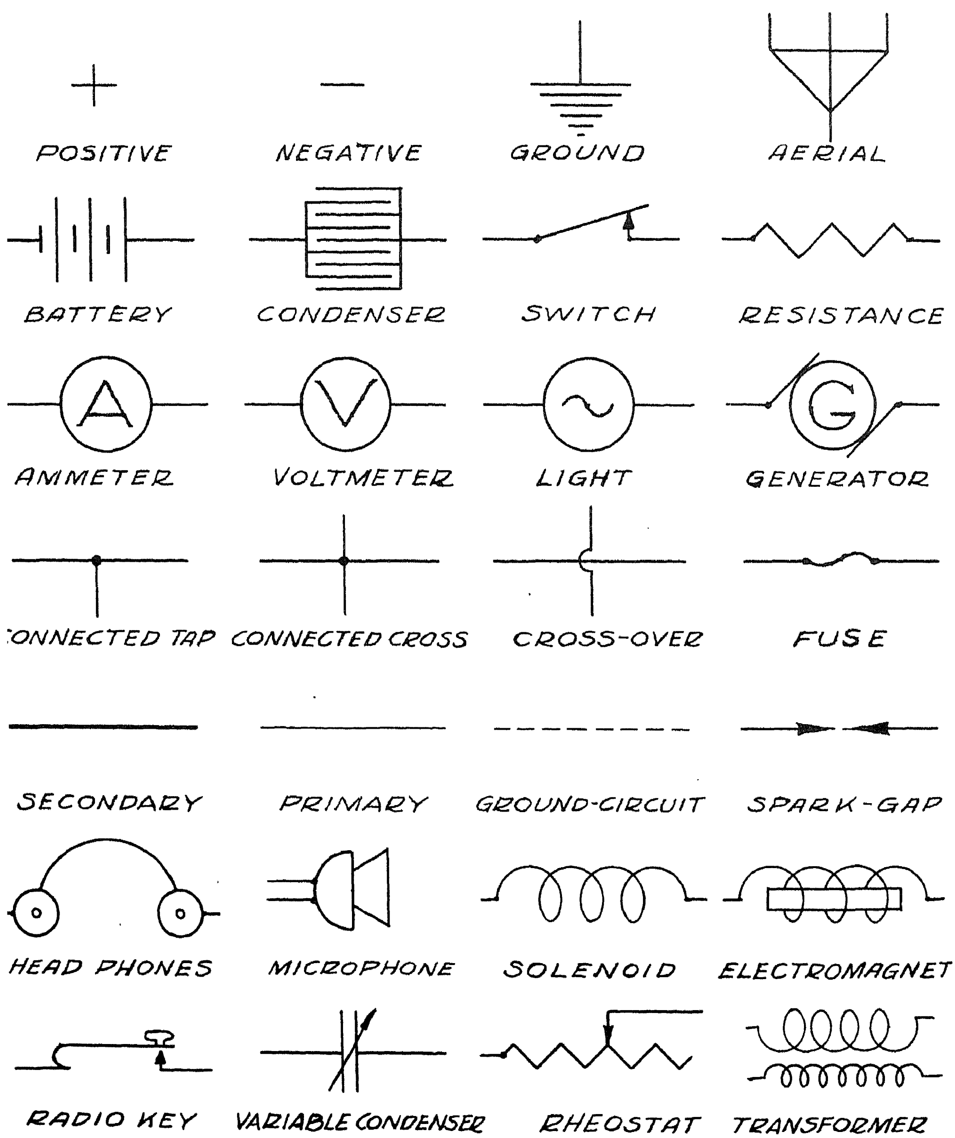
CONDUCTOR - Any material through which electricity will flow readily.

CONNECTION - Direct contact of two conductors through which a current may pass.

CURRENT - The flow of electricity in a circuit.
CURRENT, ALTERNATING - Current which changes its polarity and consequently direction of flow at regular intervals.
CURRENT, DIRECT - Current which flows in one direction only.
CURRENT, PULSATING - Current which flows with regular or varying fluctuations of intensity.
D.C. - Abbreviation for direct current, or current which flows through a circuit in one direction only.
ELECTRODE - Either the positive or the negative pole of an electric source.
ELECTROLYTE - The solution which is used in any cell. The electrolyte attacks the plates in such a manner as to produce electricity.
E.M.F. - The voltage of a current.
FLUX - The magnetic lines of force.
FUSE - A safety device designed to protect a circuit from an electrical overload.
GROUND - A common base for an electrical circuit.
HELIX - A coil of wire.
HIGH TENSION - The term applied to any circuit of high voltage.
HORSEPOWER - One electrical horsepower equals 746 watts.
INSULATOR - Any material through which an electric current will not flow readily.
INSULATION - An insulating material covering a conductor, to prevent electrical losses and short circuits.
KILOWATT - A unit for measuring electrical power, equal to 1,000 watts.
LOW TENSION - The term applied to any circuit of low voltage.
MAGNET - An object having the power to attract ferrous materials.
MAGNETISM - The power by which a magnet attracts ferrous materials.
MAGNETIC FIELD - The area affected by magnetism.
NEGATIVE - The terminal of an electric source to which the current flows from the positive terminal. Any terminal to be connected to the return or negative side of a circuit.
OHM - A unit of electrical resistance.
POLARITY - The direction of flow in a circuit. The circuit flows from positive to negative.
POSITIVE - The terminal of an electric source from which the current flows to the negative terminal. Any terminal to be connected to the positive side of a circuit.
PRIMARY CIRCUIT - Any circuit carrying a low tension voltage.
RESISTANCE - The opposition to the flow of a current in a conductor, measured in ohms.
SECONDARY CIRCUIT - Any circuit carrying a high tension voltage.
TERMINAL - A mechanical device for securing an electrical connection.
VOLT - A unit of electrical pressure, used to measure the pressure with which a current flows through a circuit.
VOLTAGE - The number of volts in a circuit.
WATT - A unit of electrical power.
WATT-HOUR - A unit for measuring electrical energy. It is the energy consumed in one hour, in a current of one ampere, at a pressure of one volt.

ELECTRICAL SYMBOLS

Electrical symbols are widely used in circuit diagrams to represent various electrical devices. A great many of these symbols have become standardized and are referred to as "conventional" symbols. A few of the more common symbols used frequently in aircraft circuit diagrams are shown below.



MAGNETISM

The ancients discovered that certain stones had the property of attracting small bits of iron. These stones were called magnets, probably because of the great numbers found near Magnesia, Asia Minor. Another mysterious property of these stones was discovered when it was found that by suspending them in such a manner that they were free to rotate, they always pointed in the same direction, approximately north and south. The Chinese are generally given credit for employing this phenomenon as early as 2400 B.C. to guide the ships at sea. Stones possessing this property were called lodestones or leading-stones and were the forerunners of our modern magnetic compass.

MAGNETIC POLES

As has already been mentioned, lodestones or natural magnets, have the power to attract small pieces of iron, but if they are dipped into a pile of iron filings and removed, it will be noticed that the iron filings cling only to the ends of the magnet. This shows that the magnetic property of the stone is concentrated at each end. (See Fig. I). The ends of the magnet are called poles. The end which assumes a north position when the magnet is suspended from a string is called the north-seeking pole, or simply the north pole. The opposite end is called the south-seeking pole, or the south pole.

ARTIFICIAL MAGNETS

If a soft iron bar is rubbed with a lodestone it becomes magnetized and will have the power to attract other iron. In this connection a peculiar thing happens. Even though the iron bar has been magnetized by the lodestone, the lodestone loses none of its original magnetism. This leads us to the conclusion that all iron has the property of magnetism but is not a magnet unless it has been magnetized.

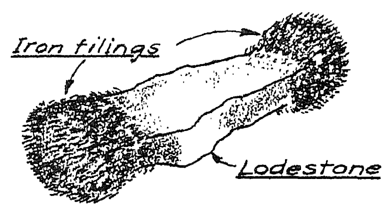
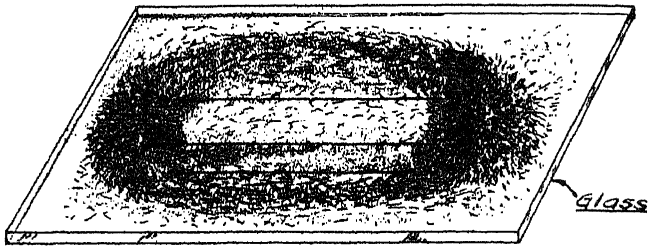


Fig. I

Note: A more practical method of magnetizing iron or steel with an electromagnet is explained later.

An iron or steel bar which has been magnetized is called a permanent bar magnet. If the iron is so shaped as to bring its poles close together it is called a horseshoe magnet. The horseshoe magnet has a stronger magnetic field than the bar magnet even though it posesses the same degree of magnetism. This is because the poles are closer together, producing a more concentrated, thus a stronger external magnetic field. The magnetic field may be defined as the area around a magnet which is affected by the force of the magnet. This can be illustrated by a simple experiment. If a bar magnet is covered with a sheet of paper or glass and iron filings then sprinkled on the paper they will arrange themselves in the manner shown in Fig. II. The lines formed by the iron filings follow approximately the magnetic lines of force. The lines of force are arbitrarily said to travel from the north pole to the south pole.

If a long bar magnet is placed in iron filings and is withdrawn



Iron filings showing magnetic field

FIG. II

it may be found that another bunch of iron filings will cling to the central portion of the bar. These filings are concentrated at what is called the consequent pole which has both north and south polarity. An extremely long bar magnet may have several consequent poles.

If a bar magnet is broken or cut each piece will have a north and south pole. Each time one of these sections is cut, its parts will form complete magnets (Fig. III).

A magnetized iron ring will attract few, if any, iron filings, leading us to believe that a ring will not become magnetized. However, if the ring is cut at any point the ends become magnetic poles. This proves that magnetic force is retained in a material until the poles are formed. By utilizing this fact the permanency of a horseshoe magnet can be retained by placing a soft iron bar, called a keeper, across its poles (Fig. IV). The magnetic field flows through the keeper and therefore does not expend its energy forcing itself through the air to the opposite pole.

When a bar magnet is suspended by a string and another magnet

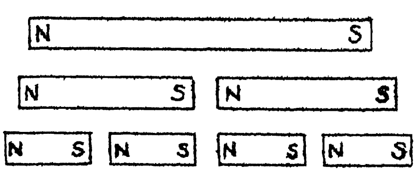


FIG. III

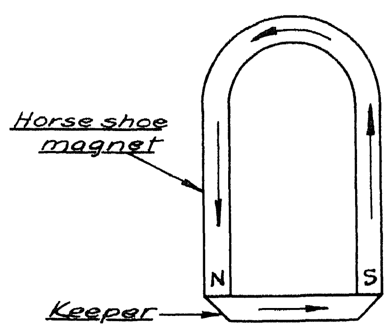


FIG. IV

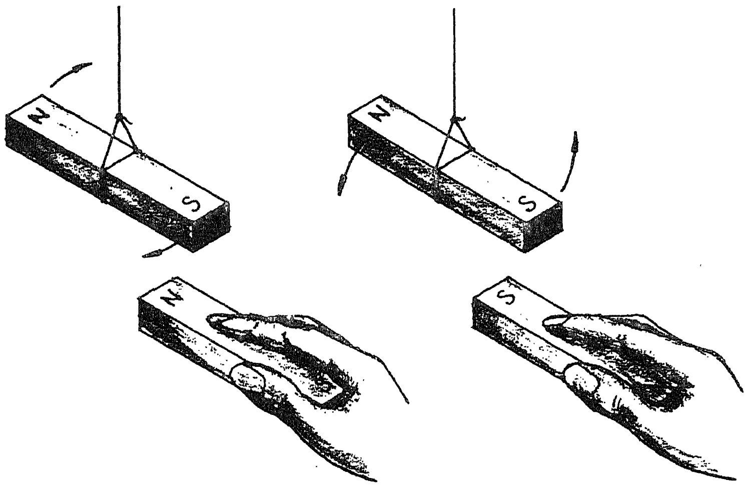


FIG V

is held near it the north pole of one magnet will attract the south pole of the other. Conversely, the north pole of one will repel the north pole of the other. Fig. V illustrates the law of magnetic attraction and repulsion which may be stated as follows: Unlike magnetic poles attract each other and like magnetic poles repel each other.

EARTH'S MAGNETISM

It is the magnetic law of attraction and repulsion which accounts for a suspended magnet pointing north. The earth itself is a huge magnet which has its magnetic poles located near its geographical poles. There have been various theories advanced as to why the earth has magnetism, one theory being that there is a huge deposit of magnetized ore in the Hudson Bay near the North Pole, and a similar deposit near the geographical South Pole. Another theory is that the earth's rotation induces a magnetism which is concentrated at the poles. Scientific observation seems to bear out the latter theory to a large extent, as magnetism has been noted on other revolving bodies.

The fact that the magnetic poles of the earth do not exactly coincide with the geographical poles accounts for the compass needle not always pointing exactly north. As a matter of fact, there are comparatively few places on the earth's surface where the compass does point due north. These points may be connected on a map with a line called the agonic line, or the line through the points where the compass error is zero degrees. If the compass is on either side of the agonic line, it points not to the geographical pole, but to the magnetic pole. The angle of this difference is called the magnetic variation. Lines through points of equal variation on the

earth's surface are called isogonic lines.

ELECTRICITY AND MAGNETISM

When an electrical current is passed through a wire, a small magnetic field is set up, surrounding the wire. As there is no insulation against magnetism, the magnetic lines of force penetrate any covering or insulation which may be around the wire. These lines of force are circular, as shown in Fig. I, but unlike those in the field of a permanent magnet, are not concentrated at the ends of the wire, instead surrounding the entire length. This field has the power of magnetizing any magnetic material that is within its range; an important fact, since it forms the basis of the electromagnet.

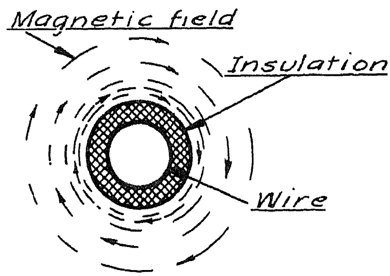


FIG. I

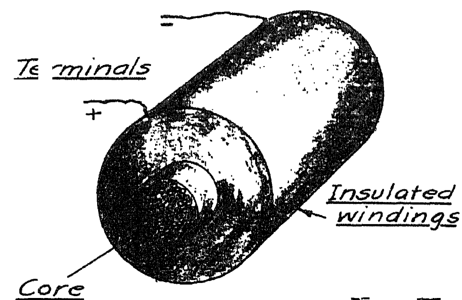


FIG. II

An electromagnet is made by wrapping insulated wire around an iron or steel bar, called a core, Fig. II. When a current is sent through the wire wrappings, or coil, the magnetic field from the wire magnetizes the core. When the current is shut off, the core loses most of its magnetism. There is, however, a small amount left. This is called residual magnetism. A hard steel core will retain more residual magnetism than a soft iron core, therefore when it is desirable to have an electromagnet lose its magnetism as soon as the current is turned off, a soft iron core is used. It has been found that a core made up of many soft iron wires will retain even less magnetism than a solid core of the same material.

The strength of an electromagnet depends upon the number of turns of wire in the magnetizing coil, or exciting coil, and the amount of current sent through this coil. The polarity of an electromagnet depends upon the direction of the current in the coils. For example, if the current goes around the core in a counter-clockwise direction the end nearest the observer is the north pole. (See Fig. III). If the direction of the current is reversed, the polarity reverses also. Thus it may be seen that if an alternating current is used to energize an electromagnet the polarity of the magnet will change with each change of direction of the current.

Solenoids - A coil of wire similar to the exciting coil of an electromagnet but having no core is called a solenoid. A solenoid possesses all the properties of an electromagnet and its strength and polarity are determined in the same manner.

If an iron bar or core is placed below a solenoid, as in Fig.

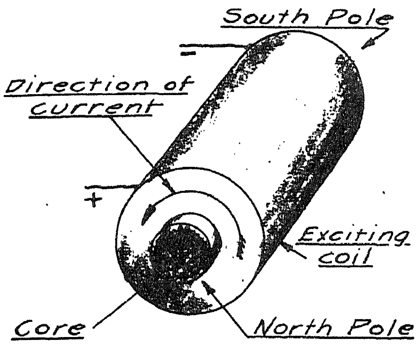


FIG. III

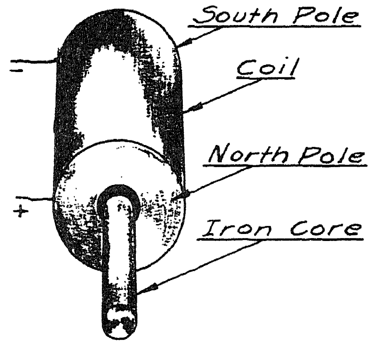


FIG. IV

IV, and the coil energized, the iron core will be drawn up into the center of the solenoid with considerable force, and will remain suspended in the center of the solenoid, not touching any side of the coil.

Probably the greatest use of the solenoid at present is in the operation of remote-controlled, heavy duty switches. The principles of the solenoid switch are illustrated in Fig. V.

View A shows the switch when the solenoid is not energized, in which case the core, with the contact bars attached, will not be in contact with the contact points. (In actual construction, a light spring is usually attached to the contact bar to insure a positive separation of the contact points.) When a current is passed through the solenoid, the core is drawn into the solenoid, as in view B, holding the contact bar firmly against the contact points, thus closing the circuit.

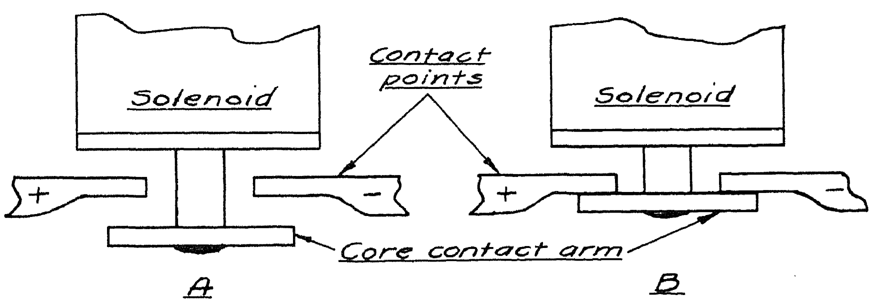


FIG. V

INDUCTION COILS

The function of the induction coil is to transform low voltage current, such as that obtained from batteries, to high voltage. High voltage current is needed to produce a spark across the points of the spark plug for the purpose of igniting fuel charges. Obviously,

therefore, the most common use of induction coils in aircraft work is to supply the high tension voltage for ignition. Examples of this application will be found in booster coils, magnetos, and battery ignition systems.

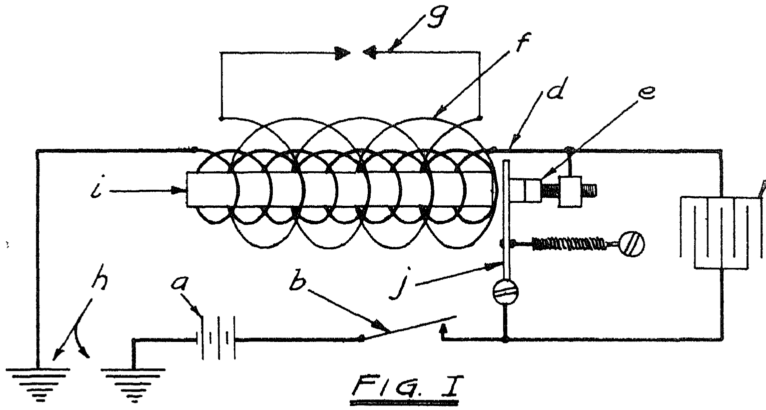


FIG. I

Vibrator Induction Coils - The battery booster coil contains a set of vibrating breaker points so arranged that the induction coil can produce a constant flow of high voltage current. As the booster coil is a complete unit in itself, its operation will be described first.

The vibrator induction coil consists of a soft iron core, a primary and a secondary winding, vibrator contact points and a condenser. A diagrammatic drawing showing the various parts and the internal and external electrical circuit, is shown in Fig. I.

When the push button b is closed, the coil is energized by current from the battery a, and a spark occurs at the gap g, which represents the spark plug. The actual operation of this coil may be explained as follows: As the primary circuit is completed by closing the push button b, the current from the battery a flows through the primary winding d, and back to the battery through the common grounds, h. The battery current passing through the primary winding magnetizes the soft iron core, i. This produces a magnetic field which passes through the secondary winding, f. However, as the magnetic field is built up gradually, the lines of force cut the secondary winding slowly, resulting in a relatively small amount of e.m.f. in the secondary winding.

Another item that must be considered at this time is the resistance of the primary winding to the flow of the primary current. This not only slows the energizing of the winding but, unless suitable provisions were made, would build up sufficient electrical pressure in the circuit between the battery and the primary winding to cause a spark to occur at the breaker points, e, when they are opened. One purpose of the condenser c, which is connected in parallel with the points, is to provide a "storage house" for electricity so that an excessive pressure will not accumulate in the cir-

cuit. The condenser is not a permanent storage place, but inasmuch as it has many plates made of a conductive material the excessive electrical pressure which accumulates is distributed over a large area on these plates. Electricity cannot flow through the condenser, as the two sets of plates are insulated from each other, therefore, the plates which are connected to the positive side of the breaker points receive a positive charge and the opposing plates receive a negative charge.

When the iron core i becomes sufficiently magnetized it attracts the movable arm j. When the arm moves toward the core, the breaker points are separated, and consequently, the primary circuit is broken. This causes the magnetic field which has been built up by the primary winding to collapse. The collapse of this field is much more rapid than its "make", or expansion. Its action can be compared to the stretching and releasing of a rubber band. When the e.m.f. in the primary circuit becomes less than the e.m.f. in the condenser, the condenser discharges through the primary circuit in the direction opposite to its original charge. This has the same effect as reversing the direction of the primary circuit, naturally resulting in a more rapid collapse of the primary flux.

The combined effects of the condenser discharge and the natural collapse of the magnetic field results in the lines of force cutting the secondary windings so rapidly that an extremely high e.m.f. is induced in the secondary. It is at this instant that a spark will occur at the spark gap g. Since the iron core is no longer magnetized and also since the condenser discharge removes any trace of residual magnetism from the core, the movable arm j springs back into place, thereby completing the primary circuit. Actually, the process of making and breaking the current is repeated so rapidly that, to the eye, a continuous spark appears at the spark gap as long as the push button is closed.

In those induction coils which are made for battery boosters, only one secondary terminal is provided. This is the positive terminal, and should be connected to the positive side of the spark plug through the magneto or distributor. The negative terminal of the secondary winding is grounded internally to the primary circuit. Obviously, the primary ground must be electrically connected to the engine, which serves as the spark plug ground.

Battery Ignition Coils - The battery ignition coil is not a complete unit, such as the vibrator coil, and in itself is not capable of producing a spark. The ignition coil consists of a core, a primary and secondary winding. The necessary breaker points and condenser are usually contained in the distributor head. In operation, the spark is not continuous, but occurs only when the breaker points are opened. The points are actuated by the engine and are so timed that they are opened only when an ignition spark is needed.

Magneto Induction Coils - The magneto induction coil operates on the same principle as the battery ignition coil. In fact the only electrical difference between the two is that the magneto generates its own primary current instead of having to depend upon some outside source, such as a battery, for its supply. Further discussion of the magneto will be found in the chapter on ignition.

SOURCE OF ELECTRICITY

PRIMARY CELLS

Fig. I shows the cross section of a simple primary cell, usually referred to as a dry cell. It is composed chiefly of a carbon rod centered in a zinc container. Between the carbon rod and the container is a powdered mixture. This mixture varies in composition but contains mainly powdered carbon that has been treated with sal-ammoniac and manganese dioxide. The "mix" is sealed in the container with various types of wax sealers. The action of the mix, often referred to as electrolyte, on the zinc and carbon produces a higher potential in the zinc container than in the carbon rod. This causes a current or flow of electricity from the zinc container to the carbon rod. The cell now has the power to cause electricity to flow from the carbon rod, through a conductor, back to the container. This external flow or circuit of electricity is, for convenience sake, said to flow from the positive (+) terminal to the negative (-) terminal.

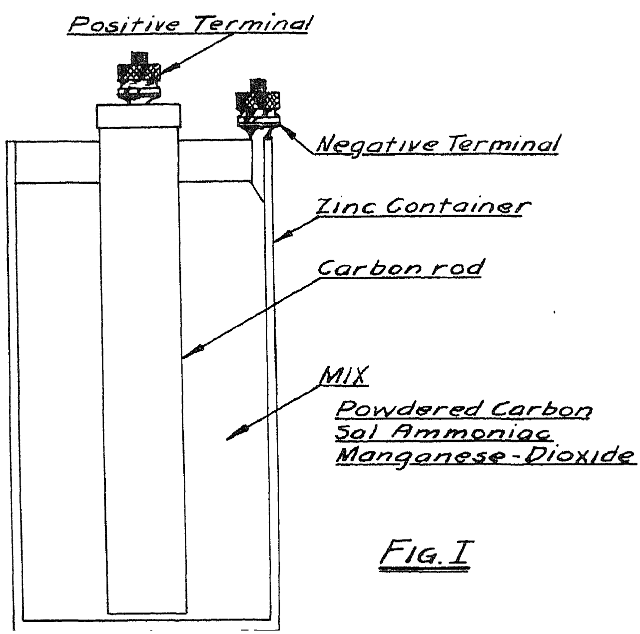
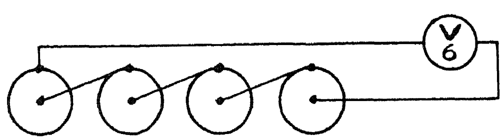


FIG. I

All dry cells of this type are capable of producing an e.m.f. of 1-1/2 volts. A standard dry cell, No. 6, measuring approximately 2-1/2" in diameter and 6" long produces a current of from 25 to 30 amperes when fresh. However, these cells lose their strength rapidly and should be tested frequently with an ammeter. Dry cells deteriorate rapidly when not in use, making it advisable to test these cells before purchasing.

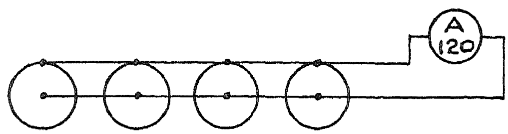


Series Connection

FIG. II

Primary Batteries - Frequently it is desirable to utilize a greater voltage or a larger current than it is possible to produce with one cell. This may be done by connecting two or more cells to form a battery. If a higher voltage is needed the cells may be connected in series.

Fig. II shows four cells connected in series (from + of one cell to - of next). The total voltage from this battery is 6 volts or equal to the sum of the voltage of the four cells. The amperage does not increase over the amperage of a single cell.



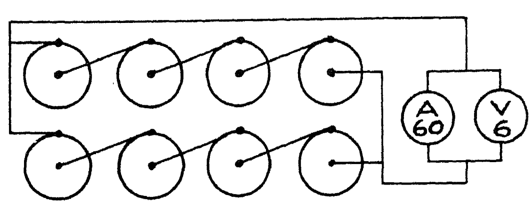
Parallel Connection

FIG. III

The amperage can be increased by connecting the cells in "parallel." By connecting the cells in the manner shown in Fig. III the amperage of each cell is added to the next so that the battery amperage will be approximately equal to the sum of all the cell amperage. The battery voltage will be 1-1/2 volts.

To increase both the e.m.f. and the current the cells may be connected in parallel-series. If it is desired to have 6 volts and 60 amperes, 8 cells will be required. They should be connected as shown in Fig. IV. Actually this consists of two batteries of 4 cells each connected in series. Each 4 cell battery produces 6 volts and 30 amperes. When these batteries are connected in parallel the voltage remains the same but the amperage doubles.

Dry cells are used on ships not equipped with a storage battery for operating booster circuits and small lighting systems. As 1-1/2 volts are usually not sufficient, dry cells are usually sold in a multiple battery. The battery may contain from 3 to 45 dry cells permanently connected in series so that the total voltage of the battery will be equal to the number of cells multiplied by 1-1/2. The high voltage dry cell batteries are widely used in radio installation.



Parallel-Series Connection

FIG. IV

SECONDARY BATTERIES

Secondary batteries, more commonly called storage batteries, differ from primary batteries inasmuch as they may be recharged after they have become exhausted. Space does not permit a thorough discussion of the origin and function of secondary batteries, however certain fundamentals pertaining to the most popular type in use today should be understood.

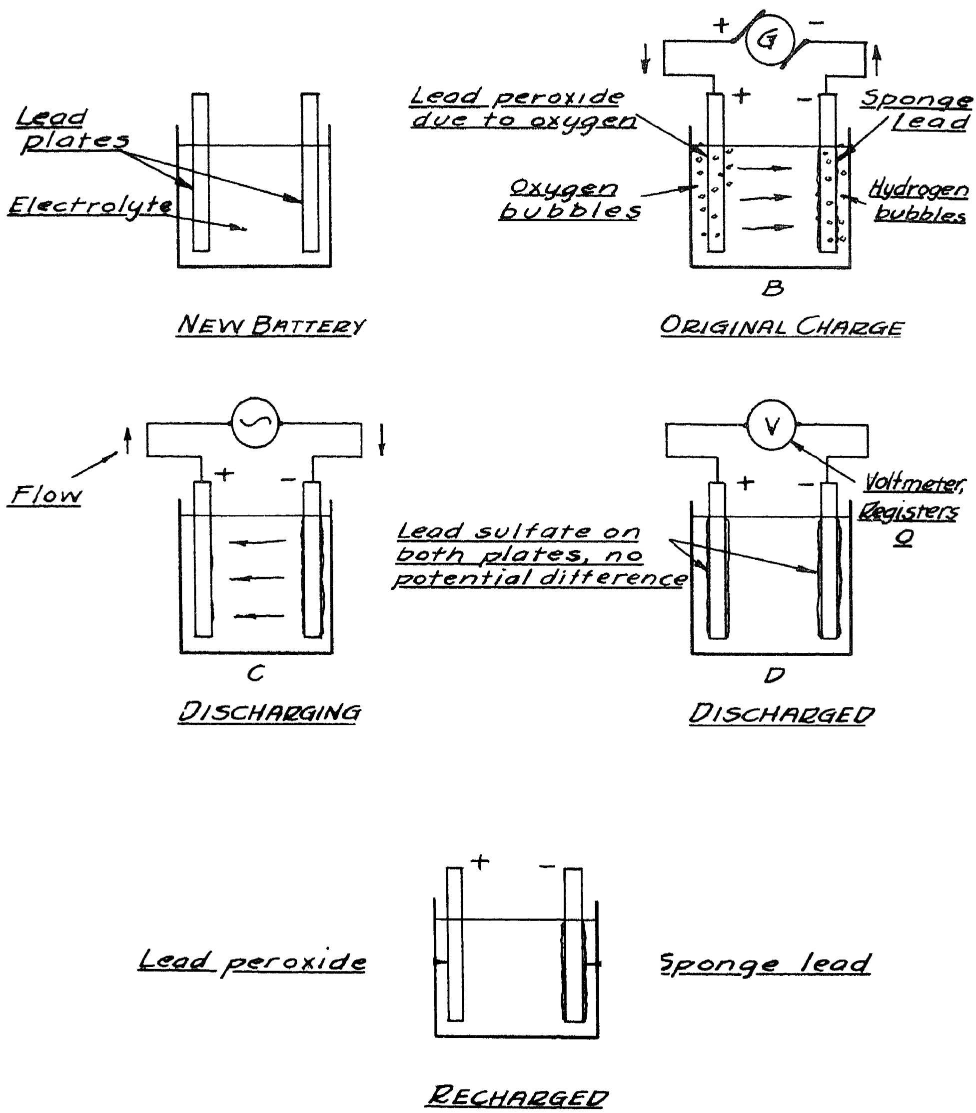


FIG. I

Practically all storage batteries used in aircraft electrical systems are of the lead-acid type. This battery consists basically of lead plates immersed in a dilute sulphuric acid electrolyte. A careful study of the illustration in Fig. I will help you to understand the various actions of the storage battery. In A, two lead plates are immersed in the electrolyte. The acid attacks both plates alike and there is no potential difference created, and neither plate has polarity. In B a current of electricity is sent through the cell from some outside source, usually a generator. As the current passes through the cell, bubbles form at both plates, however, at the plate where the current enters the cell (the positive side) oxygen bubbles are given off. This causes lead peroxide to be formed on the positive plate. At the negative plate hydrogen bubbles are given off which causes the negative plate to become sponge lead. As the cell discharges (C) lead sulphate is formed on both plates until there is an equal amount on each plate. When this happens there is no longer any potential difference between the plates and the cell is said to be fully discharged. To recharge the battery a current is sent through it as in the case of the original charge. Note: In actual practice much time is saved by the use of pasted plates. These are plates which have been previously coated by the manufacturer with an active material.

Construction of the Storage Battery - A fully charged cell of the lead-acid type produces a pressure of two volts regardless of its size. The amount of electricity produced by a cell depends upon the size or area of its plates. In order to increase the amount of electricity produced and still avoid the use of large cumbersome plates it is customary to use many plates in the same cell. All the positive plates are permanently connected to each other so that they actually form one plate. The negative plates are connected likewise.

Storage batteries used in aircraft systems have from nine to twenty-one plates in each cell, the usual number being from fifteen to nineteen plates. The plates are arranged as shown in Fig. II. It is essential that there be more negative plates than positive plates for otherwise one side of a positive plate would be exposed, in which case the exposed side of the plate would get warmer, under working conditions, than the other side, causing the plate to warp.

To prevent the plate from coming in direct contact with another, a separator is inserted between each plate. The separators are usually made of wood or especially treated hard rubber. They must be somewhat porous to permit the passage of electrolyte.

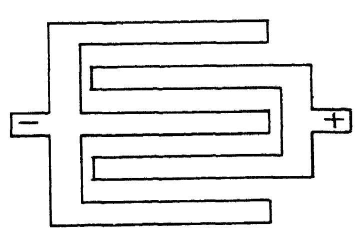
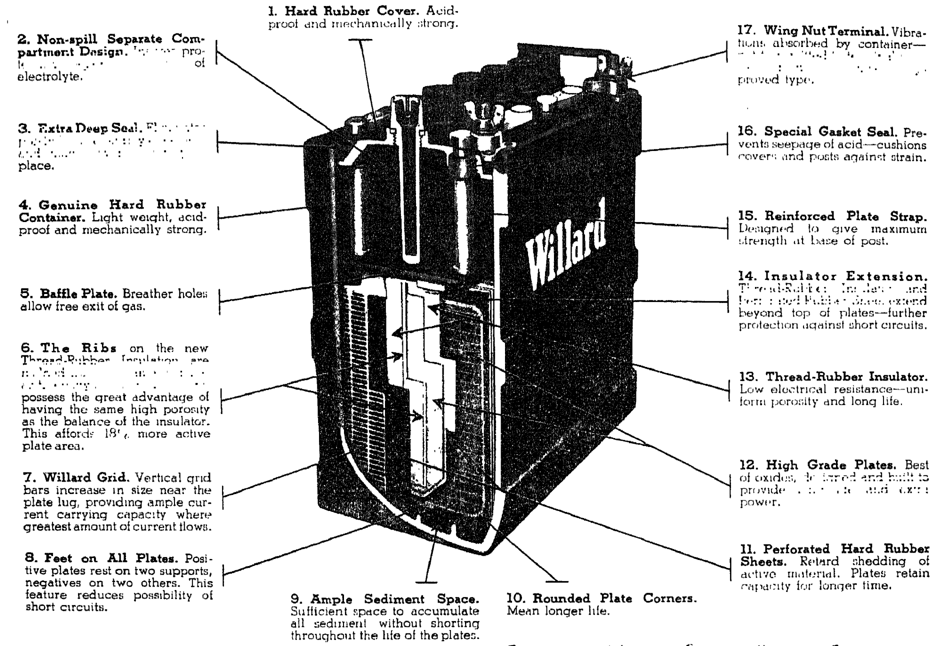


FIG. II

Most aircraft electrical systems are either six volt or twelve volt. As a secondary cell develops only two volts, the required voltage is secured by using three cells for six volts and six cells for twelve volts. These cells are permanently connected in series. The cells

are installed in a container, usually of hard rubber and sealed with pitch to prevent the loss of electrolyte.



Courtesy of Willard Storage Battery Co.

Fig. III

Fig. III shows a cut-away section of a Willard aircraft storage battery (note the positive and negative plates with separators between). Each cell must be ventilated to prevent the liberated bases from creating a pressure inside the cell. To prevent the possibility of spilling any of the electrolyte, which incidentally is very injurious to almost any part of the airplane, the aircraft battery is made with a liquid-proof chamber above the cells large enough to hold all of the electrolyte. These cells are ventilated by a long tube (see Fig. III) leading to the vent plug. When the battery is upside down the electrolyte completely fills the non-spill compartment, in which case the vent tube would act as a stand pipe preventing any leakage, yet still providing ventilation.

ELECTROLYTE

The electrolyte used is sulphuric acid diluted with pure distilled water to a specific gravity of 1.300. This number indicates the amount of sulphuric acid in the water, for example a pint of water weighs one pound. A pint of sulphuric acid weighs almost twice

as much, or 1.835 lbs. When these are mixed approximately two and a half parts of water to one part of acid, the mixture will weigh 1.30 lbs. per pint. Should it become necessary to mix new electrolyte, great care should be taken to avoid spilling any acid on the clothing or body. If any acid is spilled wash it away immediately, using plenty of water. Caution: Never add water to undiluted acid. The heat generated may be sufficient to cause steam, blowing the acid out of the container. Acid should be added to the water very slowly while stirring constantly, but gently.

The actual specific gravity can be determined by the use of a hydrometer, which is nothing more than a weighted float with a scale to determine how deep it sinks in the liquid. A fully charged battery will register 1.300. As the battery discharges some of the acid will be taken out of the solution by the plates. This lowers the specific gravity of the electrolyte and serves to indicate the state of charge of the battery. When the specific gravity of the electrolyte falls below 1.225 the battery should be removed and sent to a suitable battery station for recharging.

GENERATORS

There are two main types of generators used in aircraft; the direct current generator, which is used to keep the storage battery charged, and the magneto generator which supplies the current necessary to operate the magneto. There are many types and variations of each, however, in general the operating principles are the same.

To fully understand the operation of a generator it is necessary to accept first one of the simple explanations of magnetic phenomena.

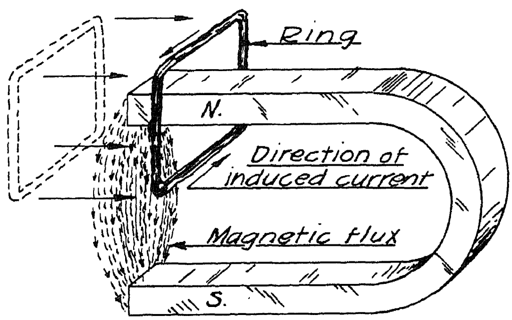


FIG. I

If a wire ring is passed through a magnetic field, Fig. I, an induced current is set up in the wire, which will be a direct current flowing in one direction only. However, if the ring is brought back through the flux, cutting the lines of force in the opposite direction, the induced electricity will be of the opposite polarity. If the wire ring is allowed to come to rest in the magnetic field, no current will be generated in the ring. The faster the wire is moved through the magnetic field the greater will be the current which is set up in the wire.

The foregoing paragraph may be summed up by the laws governing magnetic induction and expressed as follows: The strength of the current induced is directly proportional to the strength of the mag-

netic field and the speed with which the lines of force are cut. The polarity of the induced current depends upon the direction in which the lines of force are cut.

Alternating Current Generators - The principle upon which the alternating current generator operates is illustrated in Fig. II. The generator field is established by magnets to which are attached

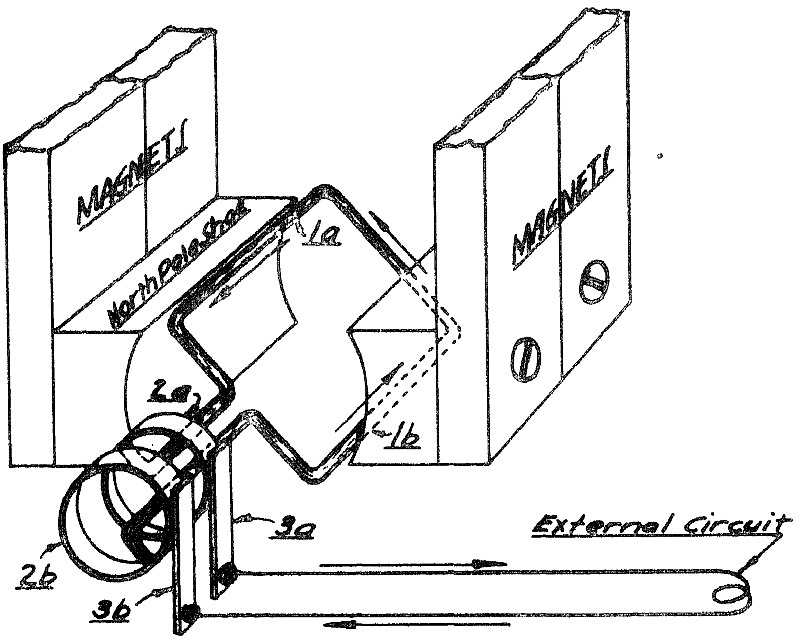


FIG. II

concave side blocks called pole shoes. The function of the pole shoes is to concentrate the magnetic field as near to the rotating armature as possible. For the sake of simplicity the armature is shown as one single turn or loop of wire. As the armature revolves, side 1-a cuts the magnetic field at the north pole, which induces a current into the wire in the direction shown by the arrow. Side 1-b is, at the same time, cutting the south pole flux which induces a current in the opposite direction. As the wire is continuous the direction of the current in the loop is in one direction only. The current flows from the armature to the commutator ring 2-a, from there through the brush 3-a and to the external circuit. The current completes its circuit by returning from the external circuit and flowing back to the armature through brush 3-b and commutator ring 2-a. When the current is flowing in this direction, brush 3-a is the positive brush and 3-b is the negative.

On the second half of the armature revolution, side 1-b cuts the north magnetic flux, which reverses the direction of the current in the wire. Likewise the current is reversed in side 1-a, thereby reversing the current in the entire loop. This time the current will leave the armature through commutator 2-b and brush 3-b and return through 3-a and 2-a, changing the polarity of the entire circuit.

Alternating current generators cannot be used for recharging storage batteries as the recharging current used for this purpose must be direct. The alternating current generator is used mostly for magneto ignition and while the constructions of magnetos differ, the principle of A.C. current generators remains the same. The application of this principle to aircraft magnetos is discussed in the Ignition section of this book.

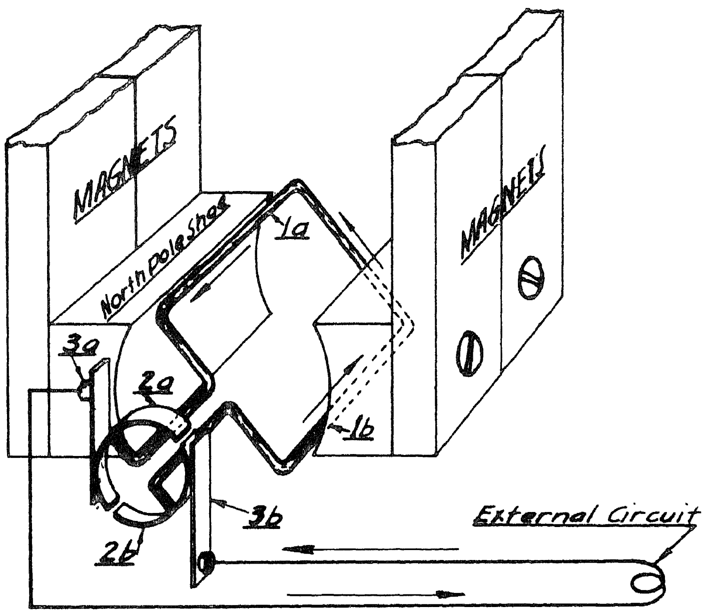


FIG. III

Direct Current Generators - A direct current generator is illustrated in Fig. III. It differs from the A.C. generator only in the manner in which the electricity is collected by the brushes. The commutator is divided into segments (2a and 2b) with one side of the armature winding connected to each segment. As the armature side 1-a cuts the north magnetic flux the current flows as indicated by the arrows, to commutator segment 2-a. From here the current flows through the brush 3-a and into the external circuit. As the current leaves the generator from the brush 3-a, that is called the positive brush. The current returns through the negative brush 3-b and the

segment 2-b and thence to the armature.

As the armature side, 1-b, cuts the north magnetic flux the current is reversed and flows to the commutator segment 2-b. However, at this point brush 3-a is in contact with segment 2-b. Therefore the current again leaves the generator via the brush 3-a. Thus the direction of the current in the external circuit remains the same.

Armatures - In the foregoing explanations of generators the armature was represented as a single loop of wire. Actually they consist of a great number of loops or turns of insulated wire wound on a core. Each continuous wire wound on a core is called a winding. A generator may have one or more windings. An armature having a single winding is shown in Fig. IV. An armature of this type for a D.C. generator would have only two segments in the commutator, each end of the winding being connected to one side or segment. While this type of armature is very effective for some purposes it is not used to any extent for battery generators as the current it produces is too fluctuating.

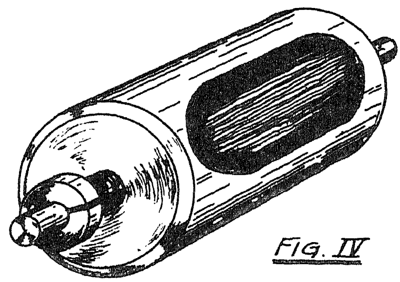


FIG. IV

Single Winding Armature

To produce a steadier current, it is customary to put several windings on the same core. Fig. V shows an armature designed to hold several windings (the windings are parallel with the slots in the core). If the generator has a two-pole field the two sides of the winding are 180° apart. That is, if the wire went through slot a, it would return through the slot which is exactly 180° opposite from slot a. On a four-pole generator the windings are between slots which are 90° apart.

Some armatures have slots which are at a slight angle, or spiral, to the axis of rotation. The spiral armature is used to effect a more smoothly running generator.

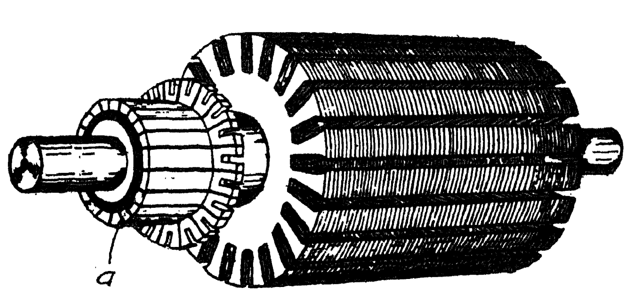


Fig. V

Commutator - As will be noted in Fig. V the commutator has two segments for every winding, each end of each winding being connected to its individual segment. In a two-pole generator it is common practice to connect the windings in parallel, or what is called lap winding. In this type of connection one side of a winding is connected to a segment and the other side of the same winding is connected to the adjacent segment. All of the windings are also connected in a similar manner. The usual method of connecting the windings in a four-pole generator is called series, or wave winding. In this method of connection the ends of the coil or winding are connected to segments which are 180° apart.

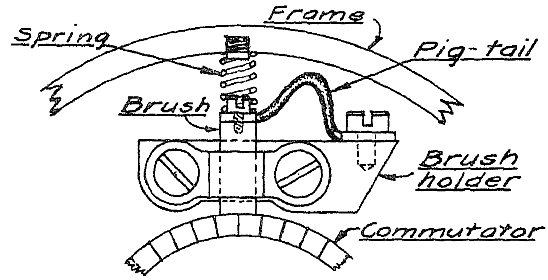


FIG. VI

Brushes - Generator brushes are made of some good conductive material such as carbon, copper, or graphite. These brushes are fitted in guides and held against the commutator by spring tension.

Generator Field - As illustrated in Fig. II the pole shoes may receive their magnetism from permanent horseshoe magnets. However, this type of field has its drawback inasmuch as in order to produce a strong field it is necessary to have several magnets, which would greatly increase the weight. In addition the magnets would require re-magnetizing at frequent intervals. Fig. VII shows the construction of a two-pole generator electro-magnetic field. The pole shoes are wound in opposite directions, thus producing a north and a south pole. Fig. VIII shows a four-pole generator. These pole shoes are wound so that the similar poles are opposite. The lines of force travel from the north to the south pole and return through the frame.

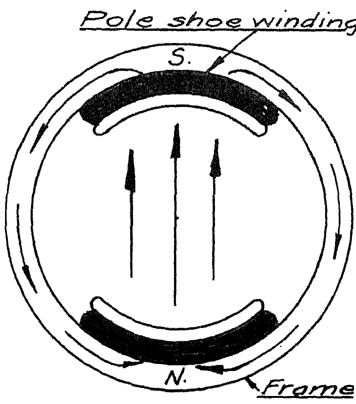


FIG. VII

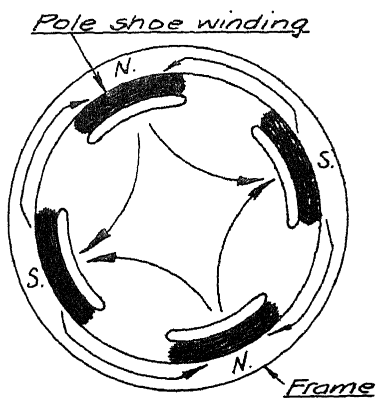


FIG. VIII

The electricity necessary to operate the electro-magnetic field is furnished by the generator itself, thus these are called self-excited generators.

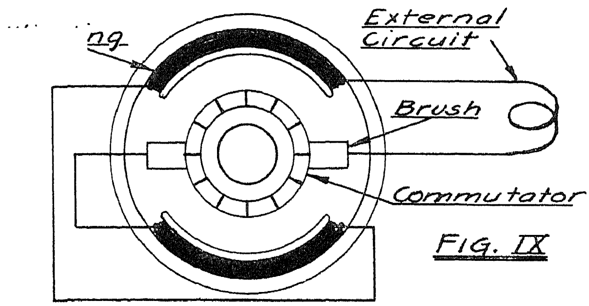


FIG. IX

SERIES WOUND

There are various ways of connecting the exciting coil windings to the generator output. One simple method is the series winding, illustrated in Fig. IX, in which all of the electricity generated must pass through the exciting coils. Another method is the parallel or shunt winding connection. In this method only a definite proportion of the current produced by the generator passes through the winding. (See Fig. X). In both types of windings the strength of the field increases as the speed of the generator increases (up to a certain point).

A compound wound field has both a series winding and a shunt winding. If both windings are such as to create the same polarity in the field, they are said to assist each other and form what we call the accumulative-compound winding. If the windings are such as to cause different polarities then they resist each other. This is called a differentially-compound winding.

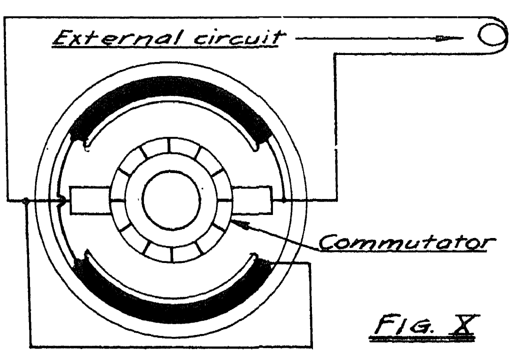


FIG. X

SHUNT WOUND

Generators having a shunt winding usually have a movable third brush on the commutator. One end of the field winding is connected to the stationary brush and the other to the movable brush. The movable third brush is, of course, located between the two main brushes. The third brush can be moved so as to intercept more or less of the commutator segments, thereby increasing the amount of electricity utilized to excite the field winding. In turn, the stronger the magnetic field becomes, the greater will be the generator output, the speed remaining constant.

INSTALLING ELECTRICAL EQUIPMENT

Electrical equipment is of unlimited value to the progress of aviation. Yet, at the same time, it can be one of its most dangerous liabilities. There is ever present the possibility of the pilot's most dread catastrophe, fire in the air. This can be caused by careless or defective electrical installations, to guard against which the mechanic should constantly bear in mind two things, to make all electrical installations mechanically and electrically secure. In order to do this the mechanic should have some understanding of the materials and methods used.

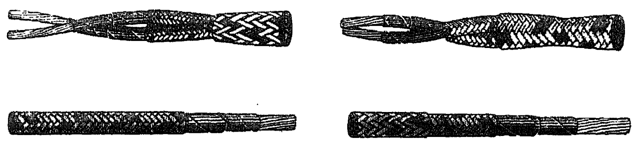


Fig. I

There are in general three types of cable used for wiring; primary, secondary and heavy duty. Note: Solid wire is very seldom used as it is likely to crystallize and crack under vibration, especially at any sharp bend.

CABLES

Primary Cables - Primary cable is used for primary, or low voltage, circuits. It is furnished in both the unshielded and shielded form, the latter for ships equipped with radio. It may also be obtained in single and double conductor cable, ranging in size from #18 gage to #6 gage. The heavier gages, #8 and #6, are used on circuits that carry a fairly heavy amount of current, such as those on the landing lights.

Copper terminals of the type shown in Fig. II are commonly used on primary cable. To attach them, about 1/4" to 1/2" of insulation is removed from the end and the exposed cable cleaned. The cable is then inserted into the small hole, where it is soldered. The wings of the terminal are then crimped around the wires and also around the portion of insulated conductor that rests on the terminal. In an emergency, where no terminal is available, a satisfactory connection can be made by removing about 1" of insulation, scraping the cable bright and bending a loop around a nail or other round object of the desired size. The excess wire is then wound back on itself so that the finished terminal will appear as shown in Fig. III.

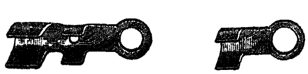
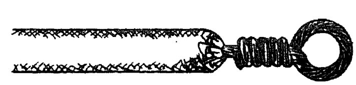


Fig. II



Emergency Terminal

FIG. III

If this type of terminal is ever used, care should be taken to place it on the connecting screw in such a manner that the tightening of the nut tends to tighten the loop. If soldering equipment is available the terminal can be made more secure by soldering the wrappings. Caution: This type of terminal should not be trusted to serve permanently.

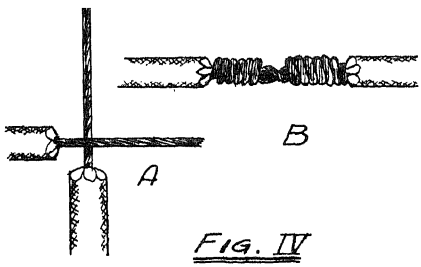


FIG. IV

To splice two primary cables together the insulation should be stripped from about 1-1/2" of each end to be spliced. The cable should be scraped clean to remove any insulation, paint or any other non-conductive material. The wires are then crossed, as shown in Fig. IV-a and the ends wrapped around the opposite wire (Fig. IV-b). The splice is now ready to be soldered. Do not use an acid type flux as the acid will cause the cables to corrode and possibly part. It is permissible to insulate the splice with friction tape only; however, it is recommended that a few turns of electrician's rubber tape be wrapped around the joint first, and the entire section then covered with friction tape. As a further protection against moisture and against the tape coming off, the finished job should be coated with gasket shellac.

A tap is a connection between one wire and some portion, other than the end, of a second wire. A tap is made by removing the insulation from about 1-1/2" of the end of the tap wire and from about 1/2" of the other wire at the point where the tap is to be made. Needless to say, great care should be taken not to cut any of the cable wires when removing the insulation. After the insulation is off and the wires are cleaned, the tap is made by crossing the cable as shown in Fig. V-A, and wrapping the tap cable around the other. The tap is then completed by soldering and insulating in the same manner as was explained for the spliced wires.

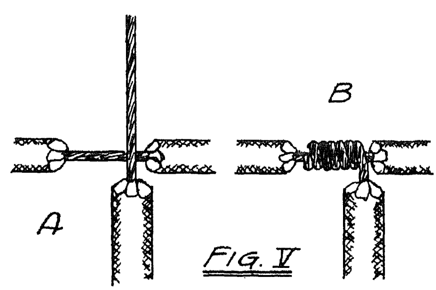


FIG. V

Secondary Cables - Secondary cable is designed to carry a high tension current. Its most common use is to carry the current from the distributor of the ignition system to the spark plugs. It does not differ much from primary wire except that the cable is heavier and better insulated. It also is supplied in shielded and unshielded form. The standard size secondary cable is 7 mm. and its use is accepted almost universally; however, in some cases a 9 mm. is used.

As secondary cable has such a limited use, being employed mainly

for ignition high tension circuits, the terminals fitted ordinarily are those which are adapted to spark plugs. (See Fig. VI). These terminals have a hard cylinder of some non-conductive material which fits over the cable insulation. This serves not only to make the connection more rigid, but prevents the possibility of electrical leakage at the terminal.

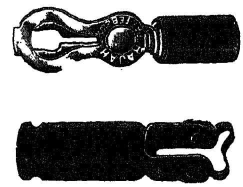


Fig. VI

The terminal is attached by removing about 1/4" of insulation from the cable and inserting the wires through the small hole at the end of the cylinder-like wire container. The wires are then spread out and soldered in place. After the joint has cooled the insulating ferrule is slipped in place and the terminal is complete.

It is not customary to splice or tap secondary cable. If this becomes necessary, it can be done in the same manner as in the case of splices and taps in primary cable. However, if the cable is to carry a high voltage the joints must be insulated with electrician's tape.

Fig. VII

Heavy Duty Cables - Heavy duty cables are used to carry a low voltage a heavy amperage. They are made to carry from 25 to 125 amperes and standard sizes are 4, 2, and 0 gage (0 gage being the heaviest). These cables may be had either shielded or unshielded. (See Fig. VII).

Heavy duty cables usually are attached at one end to the storage battery, therefore the terminal at that end is designed to fit the battery. The other end usually has a large one-piece terminal, such as shown in Fig. VIII. This is put on by removing slightly more than enough insulation from the cable to allow the wires to reach to the end of the terminal socket. The wires are then thoroughly sweated into the terminal, using a non-acid flux solder. Heavy duty cables are not spliced or tapped.

SOLDERING CABLES

There are two types of soldering coppers used for soldering wires; the plain copper, or soldering "iron", as it is called, and the electric soldering iron. Of the two the electric iron is somewhat more convenient as there is no bother about the constant reheating needed when

Fig. VIII

using a small soldering iron. Whether plain or electric, a small iron should be used when soldering splices as the larger iron radiates so much heat that it has a tendency to burn the insulation near the splice.

Soldering is one of the important duties of the mechanic and great care should be taken to do a good job. The following suggestions may prove to be of assistance:

1. Make sure that the cables to be soldered are scraped clean, free from any insulation, grease, etc.
2. Have the iron properly tinned. Note: The iron may be tinned by rubbing it in sal-ammoniac and solder, or by using rosin and solder.
3. Have the iron hot enough, yet not too hot. The iron should never be left in the flame until changeable colors appear on the surface of the copper. A little experimenting will show the best temperature.
4. Never use an acid flux as the acid has a corroding effect on the cables.
5. In many cases rosin core wire solder will be found to be more convenient than bar solder.
6. Wherever possible place the work in such a position that gravity will aid the flow of solder.
7. When soldering in a limited space, sheet asbestos or gasket material will protect surrounding cables.
8. If the soldered job has a whitish, sponge-like surface the solder was put on too cold. It should be sweated or reheated and the excess wiped off with a clean cloth.

Considerable thought and attention must be given to the proper installation of electrical cables. A carelessly placed or insecure cable may not only present an electrical hazard, but a mechanical hazard as well. A loose or broken wire may fall in the control mechanism and cause it to jam or the cable may become tangled in some of the equipment with unfortunate results. To guard against any mishaps of this nature it is necessary to make all installations secure and foolproof.

It is desirable wherever practicable to run all cables in a light weight aluminum tube. This not only makes the wiring installation look neater but protects the wires against grease, oil, dirt, moisture, chafing, etc., and reduces the fire hazard. Caution: High voltage cables should not be run in the same tube with primary cables.

Where cables go through bulkheads or fire walls they should be protected against chafing by a large rubber grommet.

If cables are to be taped to some part of the structure a good chafe pad should be provided and the taping protected with gasket shellac. Caution: Never use wire to fasten a cable to the structure as the wire might cut through insulation and a short circuit result.

CIVIL AIR REGULATIONS

There are no specific rules which will cover all cable installations and much therefore is left to the judgment of the mechanic. The Civil Air Regulations which apply to electrical installations are as follows:

"Electrical equipment shall be installed in accordance with accepted practice and suitably protected from fuel, oil, water and other detrimental substances. Adequate clearance shall be provided between wiring carrying appreciable current and fuel and oil tanks, fuel and oil lines, carburetors, exhaust piping and moving parts.

"Batteries shall be easily accessible and adequately isolated from fuel, oil and ignition systems. Adjacent parts of the aircraft structure shall be protected with a suitable acid-proof paint if the battery contains acid or other corrosive substance and is not completely enclosed. If the battery is completely enclosed, suitable ventilation shall be provided. All batteries shall be so installed that spilled liquid will be suitably drained or absorbed without coming in contact with the airplane structure.

"Fuses shall be so located that they can readily be replaced in flight. They shall break the current in a generating system at a sufficiently small current flow to adequately protect the lights, radio equipment and other parts of the circuit.

"When a generator is specified it shall have sufficient capacity to carry the entire running load. Such generator shall be engine-driven unless an approved equivalent system is provided. Auxiliary power units will be approved in lieu of batteries and engine-driven generators, provided that they are at least two in number and that the supply system is capable of carrying the entire running load with any one unit out of action.

"The running load shall be defined as the electric consumption of all lights, radio equipment and other electrical devices except those which are designed only for occasional intermittent use. Examples of devices regarded as intermittent are radio broadcasting equipment, landing lights and electrically operated landing gears and wing flaps. Radio beacon signal receivers and all other lights are considered a part of the constant load.

"Electrical installations shall incorporate a master switch easily accessible to a member of the crew."

CHAPTER 10

IGNITION

The ignition system comprises a means of producing a high tension current, wires for conducting the electricity to the spark plug, the spark plugs themselves, shielding to prevent interference with the radio when such is carried, and a switch or switches, with the necessary connections to render the system active or inoperative. There are two types of ignition systems used in modern aircraft engines. The first and by far the most common of these uses a high tension magneto, with a built-in distributor, from which a high tension current is led directly to the spark plug. The second employs a battery, a high tension coil, and a distributor connected to the accessory drive. Each system has its advantages, as will be shown later.

The Civil Aeronautics Authority requires all engines of more than 100 h.p. to have dual ignition. In the case of the magneto system, this means two magnetos and two complete sets of spark plugs. When battery ignition is used, one battery is considered sufficient, but two distributors, each with its separate spark plugs, are required. There are two advantages in dual ignition. One advantage, naturally is the added safety, since, if, for any reason, one system fails to function, the other will keep the engine running without great loss of power until repairs can be made. The second and less obvious advantage is that combustion is much more even and complete when the charge is ignited from opposite sides at the same time. The fact that this double spark increases the power can be readily demonstrated by cutting out one circuit when the engine is running at cruising speed or above. There will be an immediate loss of 25 to 75 r.p.m.

The advantages of the magneto system as compared to that employing the battery are as follows: somewhat lower weight; no likelihood of a weak spark due to a poorly charged or defective battery; less danger of fire following a crash, since, when the switch is off or when the engine is not running, no spark can be produced by the magneto.

The battery system has these advantages: the intensity of the spark is equally great whether the engine is running fast or slow, thus making for easier starting; fewer moving parts, and so eliminating possible sources of trouble; since the coil and distributors are much lighter than the magnetos, there is an appreciable saving in weight if a battery must be carried for radio, lighting, or other electrical devices.

MAGNETO IGNITION

The Scintilla magneto is used almost universally on those aircraft engines which are equipped with magneto ignition. There are many types, each designed for some specific engine or group of engines, but the basic principle of all is the same. This magneto was

originally developed in Switzerland, but is now manufactured in the United States by the Scintilla Magneto Company, a subsidiary of the Bendix Aviation Corporation. Because of this, some of the models are called "Bendix" magnetos.

TYPES OF SCINTILLA MAGNETOS

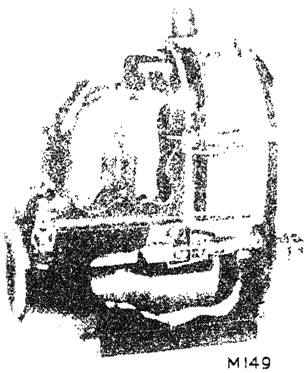


FIG. I

The AG Series - One of the most popular types of Scintilla magneto has been the model AG. Slight variations of this model are designated by another letter preceding, such as "V-AG." The number of cylinders for which the magneto is designed and other modifications of the design are indicated by a numeral and a letter following the model designation, as, for example, "V-AG9-D" for a nine cylinder engine. A cut-away view of this particular model is shown in Fig. I. Although the AG series is gradually being replaced by improved models, it is still probably the most commonly encountered and furthermore it is somewhat easier to understand than some of the later types. For this reason it is used for a discussion of the principles involved. The feature of the Scintilla magneto is its rotating magnet and stationary coil. This characteristic is responsible, to a large extent, for the dependability of this magneto, since the delicate parts do not move and consequently are not likely to be damaged. The following discussion of the electrical operation of the Scintilla magneto is supplied through the courtesy of the manufacturers, the Scintilla Magneto Company, Inc., Sidney, N. Y., and should be studied in connection with the diagram shown in Fig.II.

It should be noted that the wiring of the coil in this figure is purely diagrammatic. Many students are confused by not fully understanding the fact that the primary coil wraps entirely around the core, that the condenser is around the primary coil and the secondary coil is wound outside of the condenser. It should also be noted that the entire breaker assembly, including parts numbered 5, 6, 7, 8, 9, and 10, is not shown in its true relation to the rest of the magneto, but is drawn as it appears when viewed from the end of the magneto away from the engine. If it were shown in its actual location, the view would be from the side and the breaker lever, the points, etc., could not be clearly seen.

Magnetic Field and Contact Breaker - "The electrical circuits are shown in the 'Diagram of Electrical and Magnetic Circuits.' The rotating magnet (1) has four poles. These poles are in pairs, being connected together inside the laminated ends. The two 'N' poles make up one pair and the two 'S' poles the second pair.

"The magnet (1) rotates between the laminated pole shoes (2), producing an alternating field in the core of the coil (3), and consequently a current impulse in the primary of the coil. The coil is

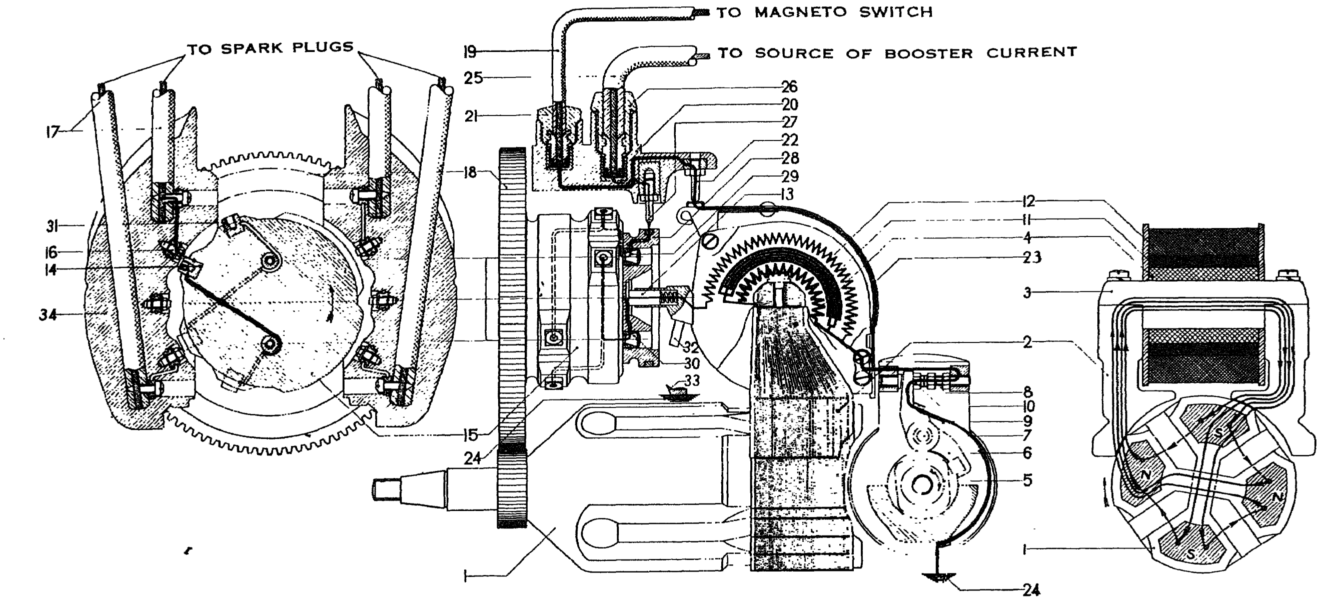


Diagram of Electric and Magnetic Circuits

1. Rotating Magnet.
2. Pole Shoes.
3. Core of Coil.
4. Primary Winding.
5. Breaker Cam.
6. Breaker Lever.
7. Breaker Lever Axle.
8. Long Contact Point (Insulated).
9. Main Spring for Breaker Lever.
10. Short Contact Point.
11. Condenser.
12. Secondary Winding.
13. High Tension Carbon Brush.
14. Segment in Distributor Cylinder carrying Secondary current.
15. Distributor Cylinder.
16. Electrode Distributor Block.
17. Ignition Cable.
18. Large Distributor Gear.
19. Ground Wire.
20. Booster and Ground Connection Block.
21. Fastening Screw for Ground Wire.
22. Stud for Ground contact.
23. Primary Bridge.
24. Ground through the Magneto and Engine.
25. Booster Cable.
26. Fastening Screw for Booster Wire.
27. Electrode for Booster Current.
28. Collector Ring for Booster Current.
29. Fastening Screw for Collector Ring (In Booster Circuit).
30. Fastening Screw for Collector Ring (In Secondary Circuit).
31. Segment in Distributor Cylinder carrying Booster Current.
32. Safety Gap Electrode.
33. Ground Plate for Safety Gap.
34. Distributor Block.

FIG. II

in reality a transformer, having a primary winding (4) consisting of relatively few turns of fairly heavy wire and a secondary winding (12) consisting of many turns of fine wire.

"When the current reaches its maximum value, the breaker cam (5) causes the breaker lever (6) to turn on its axle (7), thus opening the contact points (8) and (10).

"The cam (5) is mounted on the rear (breaker) end shaft of the rotating magnet (1), in a fixed relation to the magnetic poles.

"The short contact screw (10) is connected to ground (24) through the breaker lever (6) and the main spring for the breaker lever (9). The long contact screw (8) threads into the insulated support and is connected to the primary winding (4) by means of a laminated copper brush fastened to the primary bridge (23).

"When the contacts (8) and (10) are opened, the electric current in the primary circuit is suddenly interrupted. It is one of the characteristics of a transformer that when the primary circuit is suddenly interrupted, with consequent collapse of the electric field, a current is induced in the secondary winding, proportional to the rate of collapse and to the ratio of primary to secondary turns.

High Tension Current - "The interruption of the primary current induces a high tension current in the secondary winding of the coil (12). One end of the secondary winding is connected to ground (24) through the primary winding (4) and the core of the coil (3), while the other end terminates at the high tension carbon brush holder which is part of the coil assembly.

Distributor - "From the high tension carbon brush (13), the secondary current goes to the spark plugs through the medium of the distributor cylinder (15) and the distributor blocks (34) and the ignition cables (17).

"The high tension brush (13) makes contact with the central contact of the collector ring for booster current (28) which is secured to the distributor cylinder (15) by two fastening screws (29) and (30). The screw (30) is located in the secondary current circuit and connects the central contact in the collector ring with the conductor moulded into the distributor (15) which leads to the segment (14).

"The distributor cylinder (15) is attached to the large distributor gear (18) in a definite position relative to the opening of the contact points (8) and (10). This position is different for each rotation. The diagram applies to a magneto which rotates anti-clockwise, viewed from the drive end. The segments (14) successively register with the electrodes (16) in the distributor blocks (34) thereby transmitting the secondary current to the ignition cables (17) and thence to the spark plugs.

Safety Gap - "The magneto is provided with a safety gap. One electrode (32) of this gap is screwed into the high tension carbon

brush holder while the ground electrode (33) is on the safety gap ground plate. This gap protects the coil against excessively high voltage in case the secondary circuit is accidentally broken so that the spark cannot jump at the spark plug. In such a case the spark jumps the safety gap thus relieving the voltage in the secondary winding of the coil.

"Advance and Retard - The ignition timing is advanced or retarded by moving the breaker assembly in relation to the cam (5). The spark is advanced by moving the breaker assembly opposite to the direction of cam rotation and is retarded by moving it in the direction of cam rotation.

"Booster Connection for Starting - The cable leading from the booster to the magneto (25) is held by a fastening screw (26), in the booster and ground connecting block (20) located in the top of the main cover. The booster current is led through a conductor moulded in this block, through a small air gap to the collector ring (29) and to the booster current segment (31) in the distributor cylinder (15). The booster current then jumps the air gap to the nearest electrodes in the distributor block (34) and thence through the ignition cable (17) to the spark plug.

"When it is desired to provide a starting spark at speeds lower than the magneto will operate, a source of booster current is provided. This is usually a small high tension magneto operated by a hand crank through a gear reduction. The high tension current supplied by the booster is delivered to the spark plugs through the distributor of the magneto.

"The booster current segment (31) is so located that it trails the secondary current segment (14) and thus provides a retarded starting spark.

"Stopping the Engine - To stop the engine, the primary current is short-circuited by conducting the current around the contacts (8) and (10) and thence to ground.

"This is accomplished as follows: The insulated long contact screw (8) is connected to the end of the primary winding (4) and through the primary bridge (23) to the stud for ground contact (22) to the primary terminal in the main cover marked 'P' and carrying the fastening screw for the ground wire (21). This wire (19) goes to the magneto switch located conveniently for the pilot. The other terminal of this switch is connected to ground.

"When the switch is closed, the primary current flows around the contacts and through the switch to ground, thus stopping the ignition."

The Double Series - This is a series of double magnetos including the SC and DF models, in which there is only one rotating magnet but two pairs of pole shoes and two sets of breakers of the pivotless type. These magnetos are of the flange-mounted type and are primarily intended to be installed vertically. The distributors are not incorporated in the magneto, as is usually the case, but are

independently driven and located elsewhere on the engine. The use of this magneto is not as widespread as that of some of the other types. Two popular engines which use double magnetos, however, are the Fairchild and the Lycoming. An illustration of the Model DF assembled is shown in Fig. III and a diagram of the magnetic and electrical circuits in Fig. IV. The advantage of this type of

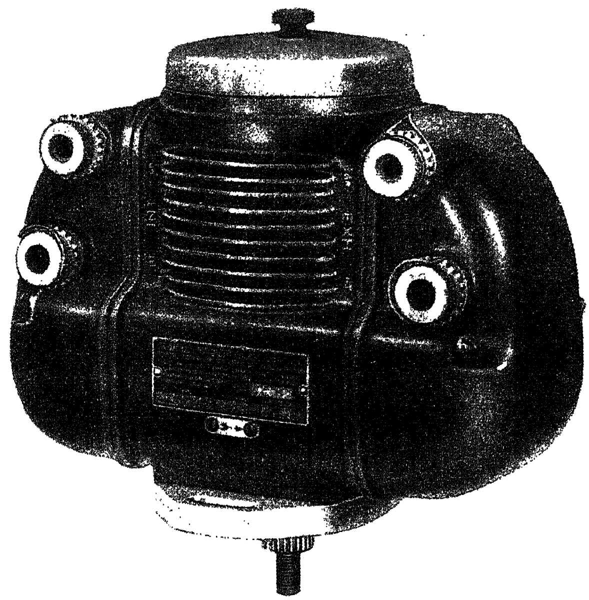


FIG. III

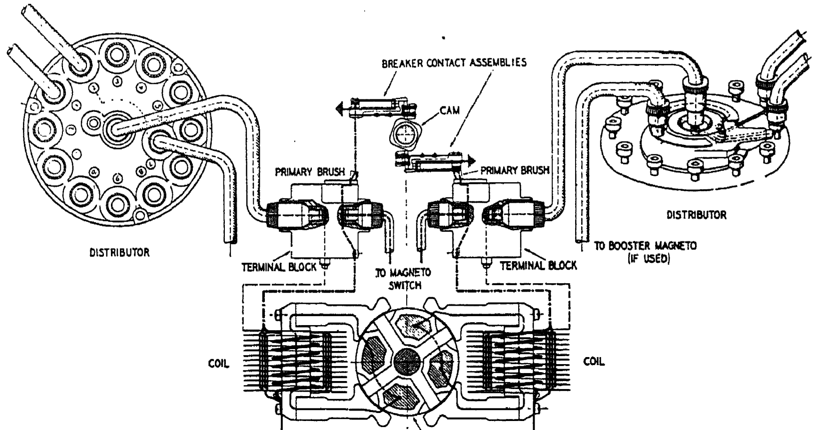


FIG. IV

magneto is its obvious saving in weight, since only one magnet (the heaviest part of the magneto) is used for both circuits. It has the disadvantage that if anything happens to the drive shaft the entire ignition system will fail to function. However, the drive shaft is usually strong and there is little likelihood of trouble occurring at this point.

The SB and SF Series - These magnetos are a later type than previously discussed, though basically the same in principle. However, the condenser is in a different location, likewise the safety gap. The magnet itself is of an improved type. The breaker points are pivotless. The method of timing is different from that used in the case of the other models just discussed. Fig. V shows an assembled view of Model SF-9LN-1. This is a flange-mounted magneto for a

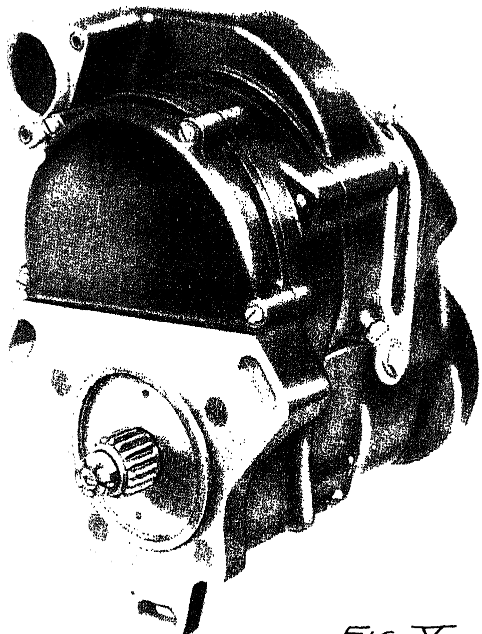


FIG. V

nine-cylinder engine, equipped with radio shielding. It is very similar to the type used for the latest fourteen cylinder engines. A diagram of the electrical circuit is shown in Fig. VI.

The N Series - These magnetos may be base- or flange-mounted and are made in three sizes, PN - D, the smallest, MN - D, the medium, and GN - D, the largest. They differ slightly in construction from other types, as may be seen in the cut-away view shown in Fig. VII. PN - D magnetos have two-pole magnets and are supplied for engines of 1, 2, 3, 4, 5, or 6 cylinders, and with four-pole magnets for engines of 7, 8, 9, 10, or 11 cylinders. GN - D magnetos with two-pole magnets are supplied for engines of 4, 5, or 6 cylinders, and with four-pole magnets for engines of 7 or 10 cylinders.

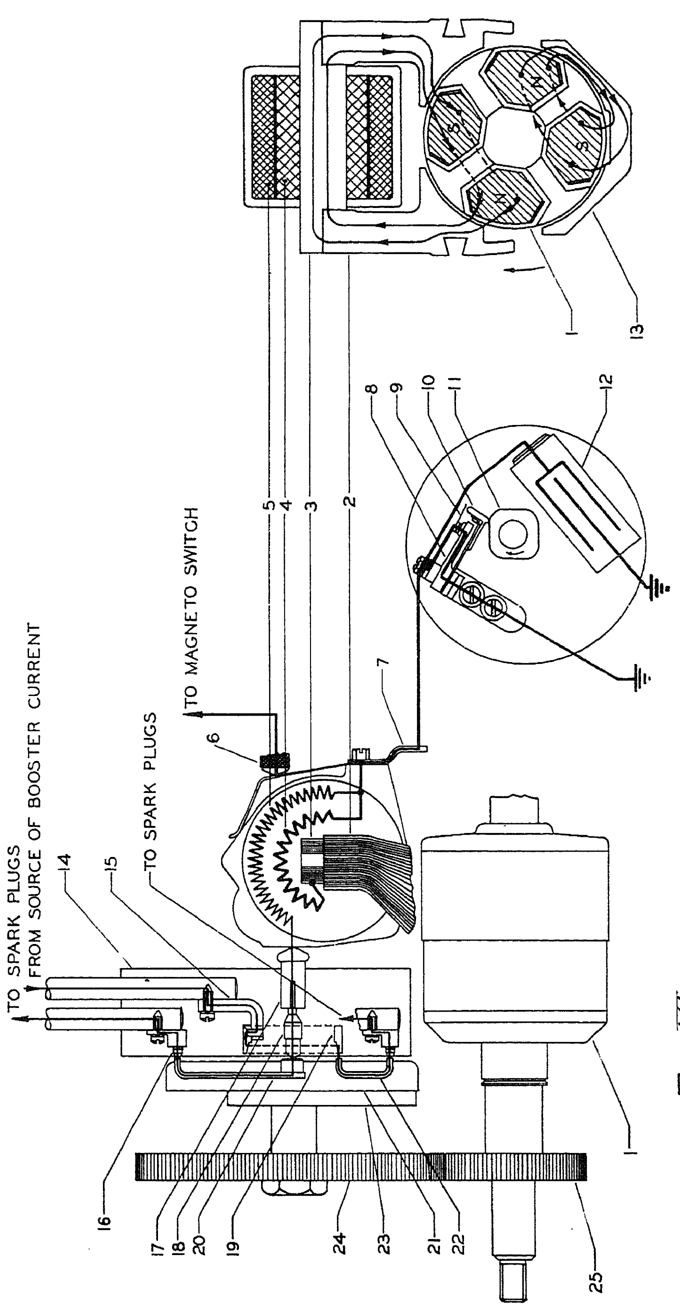


FIG VI

SCHEMATIC DIAGRAM OF ELECTRIC AND MAGNETIC CIRCUITS

1 ROTATING MAGNET
2 POLE SHOES
3 COIL CORE
4 PRIMARY WINDING
5 SECONDARY WINDING
6 GROUND CONTACT BUTTON
7 PRIMARY BRIDGE
8 SUPPORT-CONTACT BREAKER
9 SPRING-CONTACT BREAKER-MAIN
10 CAM FOLLOWER
11 BREAKER CAM
12 CONDENSER
13 KEEPER-MAGNET POLES
14 DISTRIBUTOR BLOCK
15 INSERT-BOOSTER CURRENT
16 DISTRIBUTOR BLOCK ELECTRODE
17 HIGH TENSION CONTACT BUTTON
18 CARBON BRUSH
19 COLLECTOR RING-BOOSTER CURRENT
20 SEGMENT IN DISTRIBUTOR FINGER CARRYING SECONDARY CURRENT
21 DISTRIBUTOR FINGER
22 SEGMENT IN DISTRIBUTOR FINGER CARRYING BOOSTER CURRENT
23 DISTRIBUTOR GEAR AXLE
24 DISTRIBUTOR GEAR-LARGE
25 DISTRIBUTOR GEAR-SMALL

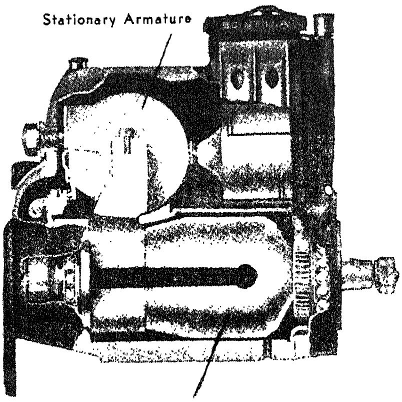
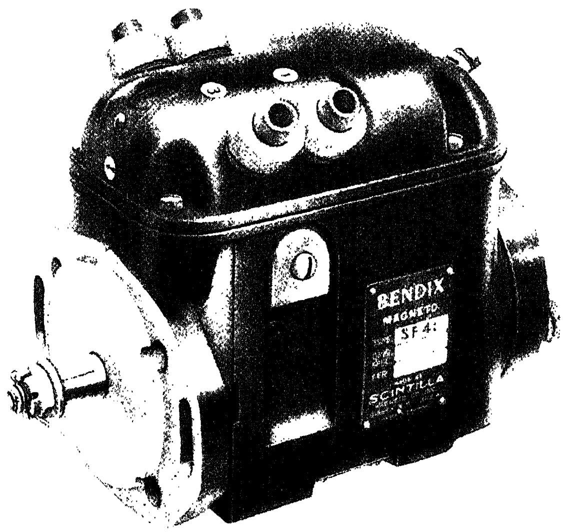


Fig. VII

GN - D magnetos for 14, 16, or 18 cylinders have eight-pole magnets. Two-pole magnets give two sparks per revolution of the magnet, four-pole magnets give four sparks, and eight-pole magnets eight sparks.

Bendix Magnetos - As previously explained, the Bendix magnetos are manufactured by the Scintilla Company. They are made for the smaller engines of four, five and six cylinders. These magnetos also carry the SF designation. The Model SF4L is shown in Fig. VIII. In general, this series is very similar to its big brother, illustrated above. The attachment of the spark plug wires is different from that in any of the other types and will be described in detail later. The method of checking timing in this series is also different from that used in the other types.



INSTALLATION OF MAGNETOS

Some magnetos are driven by means of a gear on the drive shaft and some by couplings attached in the same manner. Before installing the magneto, care should be taken to see that the gear or coupling is properly seated on the shaft and correctly safetied by means of a key, nut, cotter pin, or all three. It should then be spun by hand to make sure that the gear or coupling is running true. The magneto illustrated in Fig. I of the preceding section is of the type known as "base-mounted"; in other words, it is attached to the bracket on the engine by means of capscrews which pass up through the mounting

bracket and into the tapped holes in the base of the magneto. Other magnetos, such as those illustrated in Figs. III, V, and VII, in the preceding section, are attached to the engine by means of a flange on the magneto itself. This flange is provided with three slotted holes which fit over studs projecting from the rear of the crankcase. The holes are slotted so as to permit a slight amount of rotation to provide adjustment for accurate timing.

Installing Base-mounted Magnetos - In mounting the base-mounted type, the base and the bracket should be extremely clean, since the magneto is grounded through the base. The tapped holes in the base should be inspected to see that they are free from chips or dirt and that the threads are in good condition. If the threads are damaged they should be cleaned out with a 3/8"-16 tap. The dowel holes in the base should fit the dowel pins in the bracket accurately, but not so tightly that force is required to put the magneto in place. The capscrews which are used to fasten the base to the bracket should be checked for length, so that when they are screwed snug, they will extend not less than 7/16" nor more than 1/8" into the base. If a spline coupling is used, the coupling should be slipped on the magneto gear. It is desirable, though not essential, to set the magneto to the firing position for No. 1 cylinder. The magneto may then be mounted on its bracket, the attaching capscrews tightened and locked, by passing safety wire through the holes in the heads, running the wire in such a way that drawing it tight tends to tighten the screws rather than loosen them. Instructions for timing will be given later.

Installing Flange-Mounted Magnetos - In mounting flange-mounted magnetos, the face of the flange and the part of the crankcase with which it is in contact should be cleaned and smoothed. The mounting holes should be checked to see that they align properly and that they fit the studs. The flange should be inspected around the holes for cracks. These magnetos must be set for the firing position on No. 1 cylinder, since only small adjustments can be made after they have been attached to the engine. With the magneto set properly and the piston of No. 1 cylinder at the firing point, it may be assembled to the engine and the retaining nuts screwed on enough to hold it in place, but not too tight to prevent shifting its position through the range of adjustment provided by the slotted hole.

CONNECTING WIRING

Magneto Terminals - Reference to Fig. II in the preceding section will indicate the method of attaching the spark plug wires of the AG Series and similar types. These wires are of best quality high-tension cable, cut square at the end. Some engine manufacturers recommend that a small brass washer, known as a soldering washer, with a diameter slightly less than that of the insulated portion of the cable, be soldered to the end of the cable to prevent fraying. If these washers are used, care should be taken not to burn the insulation in the process of soldering.

The screws in the distributor blocks are removed and the wire forced down into the hole until the end butts securely against the bottom of the hole. The retaining screw is then replaced. As the screw is tightened, its sharp point pierces the insulation and

passes through the strands of the cable, thus establishing a good electrical contact and at the same time holding the cable in place.

The cables which run to the switch and booster are attached in a different manner. The terminal, which is screwed into the top of the magneto is removed and the insulation carefully cut away from the end of the cable for a distance of about 1". The bare end is then pushed into the terminal until it projects through. The strands are cut off about 1/16" from the end of the terminal, spread out and soldered in place, as indicated in Fig. I. The switch wire is low-tension cable, and the booster wire is high-tension, the same as is used for spark plug wires. The switch terminal is marked "P" (for "primary") on the magneto, and the booster terminal is marked "H" (for "high-tension").

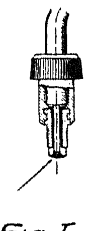


FIG. I

In the SC and DF magnetos, all the cabled, including those to the spark plugs, are connected by the method shown in Fig. I. In the SB and SF series, except in the Bendix models, the connections are quire similar to those in the AG type. In the Bendix series the cables are attached in the manner shown in Fig. II, the procedure being as follows: the knurled nut, a, the black rubber collar, b, and the rubber gland, c, are slipped over the cable. The insulation is then stripped from the end of the cable for a distance of about 1/4". The bare strands of the cable are pushed through the hole in the terminal clip, d, spread out and secured with a drop of solder. To assemble the cable to the distributor, the cable end is pushed into the terminal on the magneto until the clip engages the groove provided, after which the knurled nut is tightened.

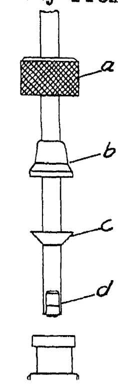
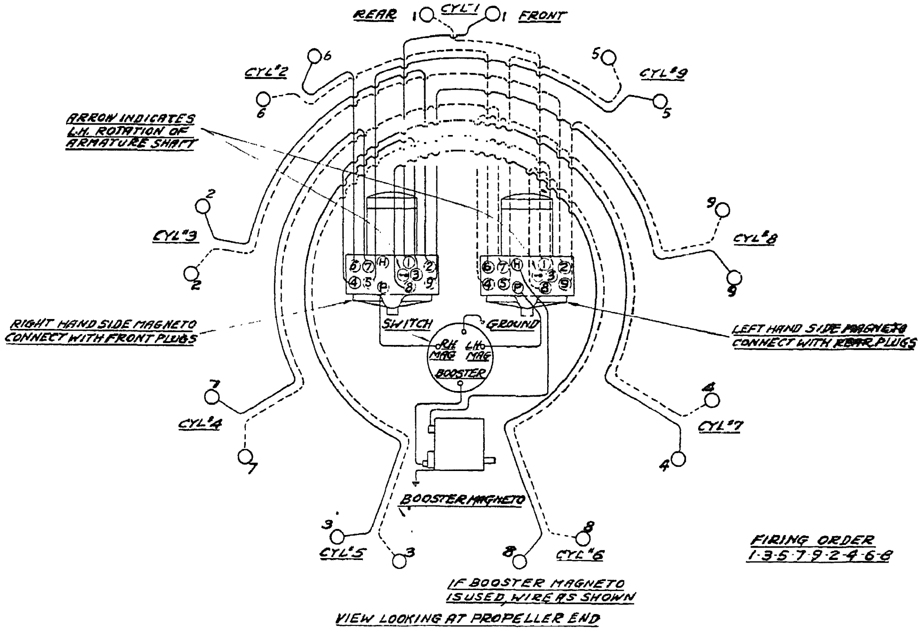


FIG. II

Ignition Wiring Diagram - In leading the wires to the spark plugs it should be remembered that the numbers adjacent to the holes in the distributor blocks are numbered, not in accordance with the cylinders, but in the order in which the magneto fires; thus while the cable numbered "1" leads to cylinder No. 1, the cable numbered "2" does not lead to cylinder No. 2, but to the second cylinder to fire. In a five, seven, or nine cylinder radial this would be cylinder No. 3. Likewise the wire numbered "3" leads to cylinder No. 5, and so on through the engine firing order. A wiring diagram for a nine-cylinder Wright Whirlwind is shown in Fig. III. This diagram includes the connections to the switch and the booster, which will be explained later.

Spark Plug Terminals - The ends of the spark plug cables which connect to the plugs must be fitted with terminals. In the case of unshielded cables the terminals are usually one of the types shown in Fig. IV. Both of these are soldered to the cable as explained in the previous chapter. The terminal shown in "A" is attached to the plug by swinging the loop, e, up until it makes an angle of approximately 90° with the cable. The yoke can then be pushed on the end of the spark plug. When the loop is brought down again into the position shown in the illustration, the terminal is securely locked in place and yet is free to swivel around the spark plug in any

direction, thus eliminating the possibility of breakage due to vibration. The terminal illustrated in "B" is provided with a flat



Courtesy Wright Aeronautical Corp.

A B

FIG. IV

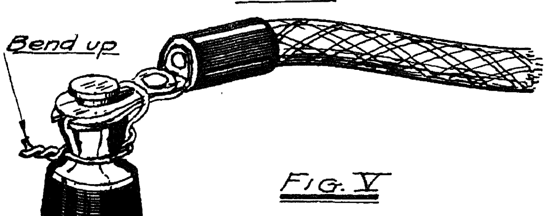


FIG. V

steel spring as a locking device. When attaching this terminal to the spark plug the spring is lifted slightly away from the brass portion, or yoke, and the yoke pushed into the groove on the end of the plug. The spring will then snap back into place around the plug, holding the terminal on. This type of terminal does not provide the universal movement permitted in the other and furthermore after long use the spring becomes bent and does not provide a sure lock. Accordingly, it is desirable to twist a piece of safety wire around the terminal and then twist the ends of this wire around the plug,

as shown in Fig. V. This will remove any possibility of the terminal's coming off. The spark plug wires should be identified by means of small brass markers similar to those shown in Fig. VI. The use of

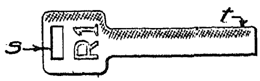


FIG. VI

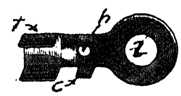
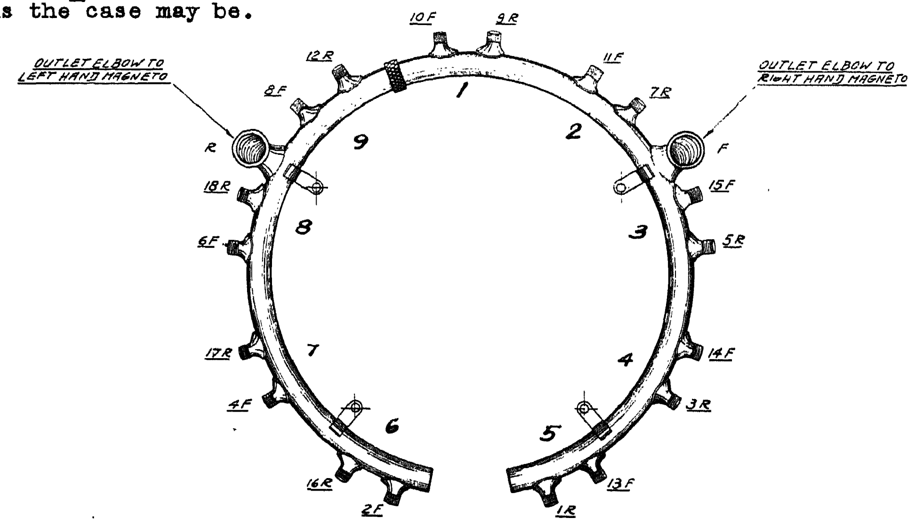


FIG. VII

these markers avoids confusion when the wires are removed during overhaul or for any other reason. The marker is attached simply by wrapping the tongue, t, around the cable, pulling it tightly through the slot, s, and bending the free end back on itself.

The end of the primary wire which attaches to the switch should be provided with a terminal similar to that shown in Fig. VII. The same applies to the end of the booster cable which attaches to the booster. The cable is attached by cutting off the insulation for approximately 1/4", passing the bare end through the small hole, h, spreading the strands over the back of the terminal and soldering them in place. The tongues, t, are then squeezed tightly around the insulated portion of the cable with a pair of pliers and the tongues, c, squeezed down in the same manner on the bare portion. The large hole, l, fits the binding post on the back of the switch or booster, as the case may be.



VIEW LOOKING FROM REAR OF ENGINE

Courtesy Wright Aeronautical Corp

FIG. VIII

In all of the larger engines, the ignition wires from the magneto to the spark plug are carried to a manifold ring, or conduit, which is bolted to the crankcase. Such a ring is shown in Fig. VIII. The one illustrated is intended for radio-shielded ignition wires

but is very similar in appearance to the type used when the wires are not shielded. All of the wires which run to the front plugs pass into one large outlet and those to the rear plugs into another, designated "F" and "R" respectively in the illustration. The wires to the individual cylinders lead from the smaller outlets. Installing the wires in the manifold is not a simple job, particularly with respect to the last few. The lengths of the separate wires are usually given in the handbook of the engine, but if this information is not available, the old wires can be used for determining the length of the new ones. The longer wires should, as a rule, be worked in the manifold first. The Wright Aeronautical Corporation recommends the sequence indicated, in Fig. VIII by the numbers and letters adjacent to each outlet. The numbers on the inside of the ring indicate the cylinder to which the respective pairs of outlets lead. The numbers on the outside of the ring must not be confused with the numbers of the cylinders. The first wire which should be installed is designated at the outlet by the numeral "1" and the letter "R", the "R" meaning "rear." By referring to the wiring diagram in Fig. III it will be noted that this wire leads to the terminal No. 3 on the left magneto. The next wire to be installed is designated on the manifold drawing by "2F." This wire leads to terminal No. 8 on the right-hand magneto. The third wire to be put into the ring is designated by "3R". This leads to terminal No. 7, on the left magneto, and so on. The cables should not be pulled through the ring. They should be dusted with talc and pushed in through the small outlets. When the end of the cable appears at the large outlet labelled "R", or "F", depending on whether it connects to a rear or front plug, it should be directed through the opening by means of a small wire hook. Each cable should be completely installed and brought out through the large opening before starting the next. Great care should be taken to avoid abrasion or other damage to the cables while installing them in the manifold ring. A break in the protective coating allows the rubber to be attacked by heat and oil and may eventually cause a short circuit. Such a short circuit will result in the failure of the plug to which the cable is connected. A short of this nature is extremely difficult to locate and may require disassembling the entire "harness." Soldering washers should be attached to the magneto ends, which should then be marked with identification tags as previously described, and fastened into the distributor blocks, as instructed above. If no identification markers are available, the numbers may be stamped on the soldering washers. If the magneto ends are too long, as much as possible should be fed back into the manifold ring. The manifold ring may now be bolted to the engine and the spark plug terminals connected.

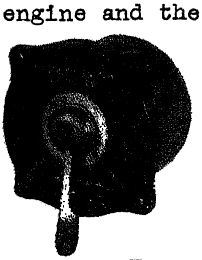


FIG IX

Ignition Switch Connections - A cockpit switch is shown in Fig. IX. On the back of this switch will be found binding posts labelled, respectively, "R", "L", "B", and "G", or in some similar manner. The primary wire from the left magneto is connected to the "L" terminal on the switch and the primary wire from the right magneto to the "R" terminal. The primary wire from the booster is connected to "B", and from the terminal marked "G" a primary wire is run to a ground connection. If there is a definite and positive electrical connection between the engine and the engine mount

and between the engine mount and the frame of the fuselage, the ground wire may be connected to some convenient point on the fuselage. However, it is decidedly safer to carry this wire to some part of the engine itself and secure it under a nut, such as one of the crankcase nuts. This procedure is essential if the engine is rubber mounted, or if there is not a metal-to-metal contact straight through from the engine to the fuselage. It should be remembered that if the ground wire does not make a circuit, either through faulty connections, or through its being broken, the engine cannot be turned "OFF", since the only way in which the magneto can be rendered incapable of giving a spark is by grounding the primary circuit.

The booster wire which runs from the terminal marked "H" on the magneto to the high-tension connection on the booster must be carefully installed to prevent chafing, since, if a short occurs as a result of the insulation being rubbed off, not only will the booster become ineffective as regards starting the engine, but when it is operated it may produce a spark at the point where the insulation is damaged. If this should happen to be in the vicinity of a leaky gas line, a fire would result. Magneto and battery boosters are discussed in detail later.

Installing Shielded Ignition Wires - If the airplane is equipped with radio, the ignition system must be shielded to prevent interference. This shielding is accomplished by completely enclosing all parts of ignition systems in metal housings. A magneto, equipped for shielding, is shown in Fig. V of the preceding section. It will be noted that the distributor blocks are completely enclosed by a housing with a single outlet. To this outlet is bolted a flexible metal conduit which extends from the magneto to the manifold ring shown in Fig. VIII. From the manifold ring each wire is likewise enclosed in a similar, though smaller, conduit which extends to the spark plug. The spark plug itself is of slightly different external construction, which will be illustrated later. The spark plug ends of the wires are not fitted with the terminal illustrated in Fig. IV since these would present considerable difficulty with respect to shielding. Instead, a terminal such as that illustrated in Fig. X is used. The spring at the end permits the shielding conduit to be screwed on the spark plug and at the same time insures that there is a contact between the cable and plug regardless of how far the screw connection is tightened. To attach the cable to this terminal the insulation is cut squarely from the cable so that 1/4" of the strand of wire projects. The sleeve is pressed over the cable until the bare end comes through the center hole in the ferrule. The strands are then bent over and back upon the nipple, divided evenly around the circumference and pressed firmly in place. None of the wire strands should extend nearer than 1/32" to the outer edge of the ferrule. A small drop of solder may be used to insure that the wires will remain in place. The terminal illustrated is made by the B-G Corporation.

FIG. X

One of the most popular types of shielding is that manufactured by the Breeze Corporation. This company manufactures entire shielding systems, including the manifold ring, the flexible conduits, and

the shields for the spark plugs themselves. The Breeze Spark Plug has the distinct advantage of being adaptable to any standard spark plug. Fig. XI shows the exterior of this shield, and Fig. XII shows a section of the unit with flexible conduit and ignition cable. It will be noted that the method of attaching the cable is very similar to that used in the AG magnetos.

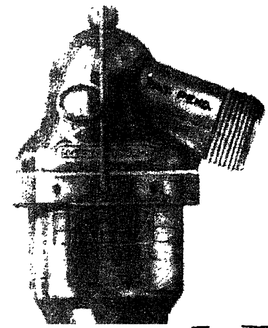
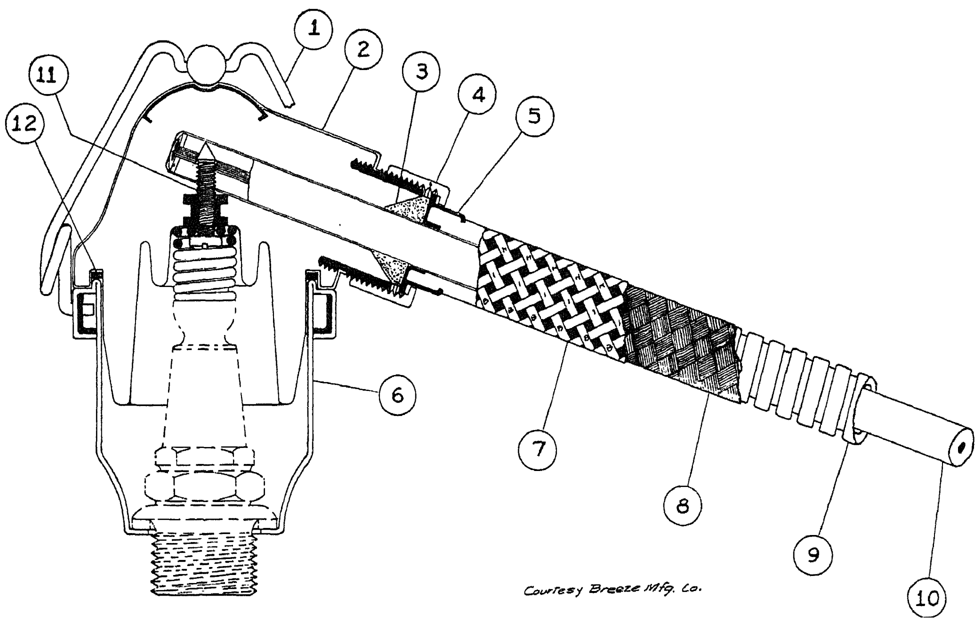


FIG. XI

If it becomes necessary to replace any of the flexible conduits, particular care must be used in cutting the material. The conduit should be wrapped with a piece of friction tape or gummed paper at the point where it is to be cut, to prevent the braid from unravelling during or after cutting. The conduit must be held in a special block, as illustrated in Fig. XIII.



Symbol No.
1 Clamp—Spark Plug Shield Cap..............
2 Cap—Spark Plug Shield (Assembly)..........
3 Gasket—Rubber Packing...................
4 Nut—Coupling..........................
5 Ferrule—Spark Plug Conduit................
6 Body—Spark Plug Shield No. 5 takes all plugs up to 1⅝ in. in length...................
Body—Spark Plug Shield No. 6 takes all plugs up to 2 in. in length....

Symbol No.
7 Armoring—Phosphor Bronze Ribbon......
8 Braid—Tinned Copper Wire............
9 Conduit—Aluminum with Asbestos Packing.
10 Cable—High Tension Ignition.............
11 Contact Retaining Screw and Spring Assembly
12 Gasket Rubber...

This block may be obtained from the Breeze Company or it may be made of wood. Its construction is obvious. The block should be held in a vise as shown. The cut should be made in the center of the tape so

that half of the tape is left on each side of the cut. A hacksaw blade with thirty-two teeth to the inch should be used for the cutting operation. It is desirable that the set be ground off the teeth of the hacksaw so that the blade is slightly knife-edged. The ferrule (Part No. 5 in Fig. XII) must be swaged on with a special swaging tool of either the bent or hand type, manufactured by the Breeze Company.

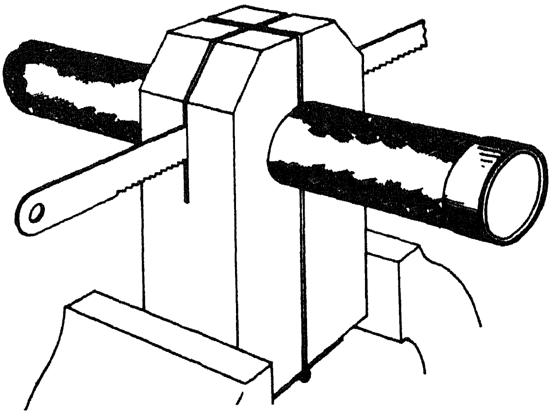


Fig. XIII

The general procedure in installing shielded systems is the same as previously discussed for the unshielded. For the switch and booster connections, shielded cable may be purchased. Cable of this type does not require a separate conduit such as that mentioned previously. Furthermore, since there is no current passing through the switch or booster connections when the engine is running, the matter of shielding them is of less importance.

TIMING AND SYNCHRONIZING MAGNETOS

Timing AG Series Base-mounted Type - On these magnetos the opening of the breaker points may be adjusted closely by means of the coupling. After the magneto is mounted on its bracket, the engine is turned in its direction of normal rotation until the No. 1 piston is on the firing point. This point may be determined by the use of a timing disc attached to the crankshaft or by means of a timing pointer supplied by the engine manufacturer. The firing point for each engine must be learned from the instruction book of the engine in question. In most cases it is in the neighborhood of 25° - 30° before top center. With the No. 1 piston set at the firing point, remove the distributor blocks and the breaker box cover and rotate the magneto by hand until the timing marks on the large gear coincide with the timing marks on the end plate. See Fig. I. These marks consist, respectively, of single and double scribe marks, on the gear (A-A) and likewise on the housing, (B-B). The single mark on the gear should line up with the single mark on the housing and the double mark on the gear with the double mark on the housing. When the gear is in this position and the breaker assembly in the fully advanced position, the contact points, or breaker

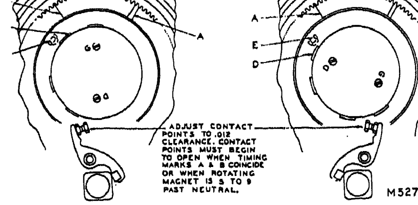


Fig. I

points, should be at the instant of opening, and the proper segment in the distributor cylinder is under the No. 1 distributor block electrode. In other words, a spark would be about to occur in the No. 1 cylinder if the engine were running. Holding the magneto in this position, connect the magneto with the magneto drive on the engine by means of the coupling. If this coupling is of the spline type, a certain amount of manipulation may be necessary before it drops into place. When the coupling is in place and safetied, the magneto is properly connected. The same procedure is then followed with the other magneto.

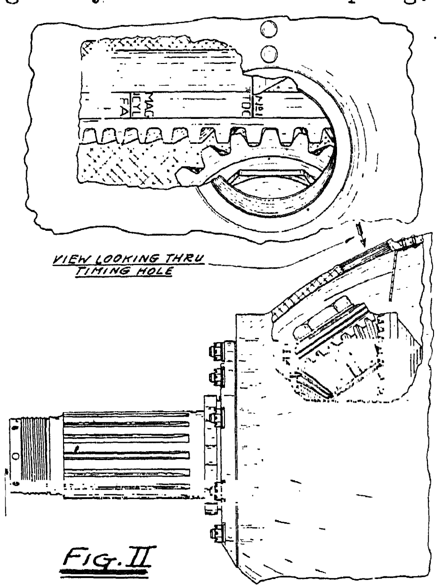


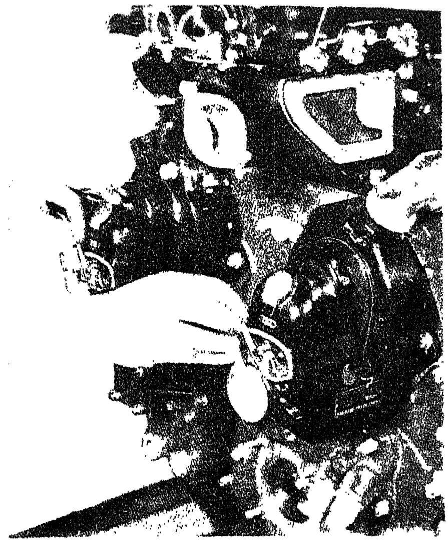
FIG. II

Courtesy Wright Aeronautical Corp.

The foregoing instructions apply to direct drive engines. In the case of geared engines, it is difficult to use a conventional timing disc, since the crankshaft and propeller hubs do not rotate at the same speed. However geared engines are provided with some means, usually marks on the gears which may be seen through a breather, or timing plug hole in the nose section of the crankcase. A typical set of such marks, used on the Wright Cyclone with 8:5 reduction gear is shown in Fig. II. It will be noted that there are scribe marks on the surface of the gear, and a pointer on the crankcase. In the view shown, the scribe mark indicating that No. 1 cylinder is on top dead center is in line with the pointer. To the left will be seen the mark indicating the firing point, with the spark fully advanced for No. 1 cylinder. Other makes and models of engines have various arrangements for checking the magneto timing. These must be ascertained from the instruction book published by the manufacturers.

Synchronizing Base-mounted Magnetos - To check the timing and synchronizing of the magnetos, the breaker box should be removed, if it is not already off, the breaker points on both magnetos should be separated with the fingers and a small strip of cellophane inserted between the points. The crankshaft is rotated in its normal direction until the piston in No. 1 cylinder is approaching the firing point. The strips of cellophane are caught between the thumb and forefinger, as shown in Fig. III, and a slight tension exerted, but not enough to pull the strips from between the closed point. The crankshaft is then turned very slowly and carefully by an assistant until the strips are released by the opening of the points. One satisfactory method of moving the crankshaft through minute amounts is by "bumping" it, that is, striking the propeller or crankshaft wrench with the fleshy part of the hand. Both strips should become free at the same time and just as the No. 1 piston reaches the firing point. If the strips are not released simultaneously, or if they are not released just as the piston reaches the firing point, one or both couplings must be disconnected and reset, and the procedure

repeated. In some engines the magnetos are set to fire at slightly different points, usually within five degrees of each other. In such cases, the check with the cellophane must be made independently on each magneto.



Courtesy Wright Aeronautical Corp.

FIG. III

Timing and Synchronizing Flange-mounted Magnetos - In this type of magneto it is not possible to obtain close adjustment by means of the coupling, since the magneto gear meshes directly with the driving gear inside the engine. However, as previously explained, the mounting holes on the flange are slotted, thus providing a certain amount of adjustment by rotating the magneto after it is set on the mounting stud. Before the magneto is put on the engine, the No. 1 piston must be set at the firing point, as described in the preceding paragraph. The magneto is then rotated by hand until the timing marks coincide, as explained above. With the magneto gears held in this position, the magnetos are assembled to the engine. Each magneto should be moved to the extreme positions allowed by the slots in the mounting flange and the breaker points watched to see that they open and close. If the points do open and close, the flat washers and nuts may be assembled on the magneto studs and the nuts tightened enough to hold the magneto in place, but not too much to prevent adjusting its position. If the points do not open and close when moving the magneto on the studs, the magneto should be withdrawn from the engine, the distributor gear reset and the magneto then replaced, engaging the magneto gear one tooth further around.

With the No. 1 piston set at the firing point, the magnetos should be moved in the direction of crankshaft rotation as far as they will go and cellophane strips inserted as before. Each magneto is then tapped back, (with the hand or a soft rubber mallet) opposite to the direction of propeller rotation, until the strips of paper are just released, indicating that the breaker points are beginning to open. The nuts which hold the magneto to the engine should then be tightened. The setting should be checked by turning the crankshaft backward about a quarter of a revolution, replacing the cellophane strips between the points, and moving the crankshaft slowly and carefully ahead until the strips are released. Both strips should be released at the same time and the timing disc, or timing marks, should indicate that the No. 1 piston is on the firing point. If the magnetos do not check properly, they must be loosened and reset. When the settings are correct, the retaining nuts may be checked for tightness and safetied.

Timing Double Magnetos - The procedure in timing these magnetos

is the same as that just discussed for any flange-mounted type, except that the magnetos do not have to be set for any particular cylinder, due to the fact that the distributors are independently driven. Accordingly, all that is necessary is to mount the magneto, leaving the retaining nut loose enough to permit rotation, place a strip of cellophane between the points and with the No. 1 piston on the firing point rotate the magneto on its mount until the cellophane is released, after which the retaining nuts may be tightened and safetied.

The distributor heads used with double magnetos are mounted and driven at one-half engine speed, independently of the magneto. The distributor finger is mounted underneath the head on a centrally located drive shaft. An insulating disc located under the distributor finger has engraved marks indicating the rotation and the position of the finger for firing No. 1 cylinder with its piston at full advance position. With No. 1 piston at its firing position for full advance spark, place the insulating disc in position and adjust and secure the distributor finger until it coincides with the marks on the disc indicating full advance for the given rotation.

Timing and Synchronizing the SB and SF Scintilla Magnetos - Except for the location of the timing marks the procedure of these magnetos is the same as with all others previously discussed. With the main cover, breaker cover, and distributor blocks removed and with the piston of No. 1 cylinder set at the firing point, the magneto should be rotated by hand until the scribe mark on the distributor finger lines up or indexes with the timing mark on the indicator at the top of the front end plate. In this position the high tension electrode of the distributor finger will be directly opposite to No. 1 electrode of the distributor block. Install the magneto on the engine with the distributor finger in this position, but before tightening, check the opening of the point with a strip of cellophane as in the case of the other magnetos. It should be remembered that in timing, all adjustments must be made at the drive end and not by altering the setting of the breaker contact.

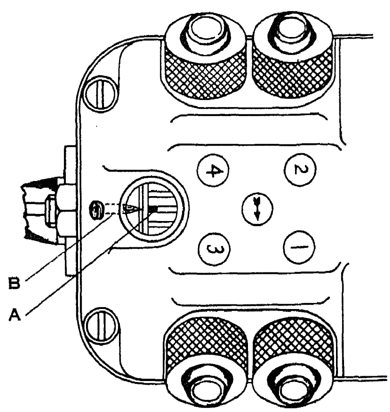


FIG. IV

Timing and Synchronizing the Bendix Magnetos - The procedure here is also the same except with respect to the timing marks. The No. 1 piston is brought to the firing point. The magneto is rotated by hand until the timing mark "A' in Fig. IV, and the timing mark "B", as seen through the timing window of the magneto cover, are in line with each other. The magneto is installed in this position and checked with cellophane as in the case of the other types.

Timing and Synchronizing with Impulse Couplings - The impulse coupling is a device to make starting easier in the case of small engines not equipped with a starter or a

booster. It is connected between one of the magnetos and the magneto driving shaft on the engine. Since the "hotness" of the spark produced by the magneto depends on the speed with which the magneto is turning, the purpose of the impulse coupling is to produce momentarily a high rotational speed of the magneto while the engine is being turned slowly. This is accomplished by means of a spring and ratchet device in the coupling. When the engine is turned slowly, this coupling does not turn the magneto to which it is attached. Instead, a spring is wound up inside of the coupling and when one of the pistons has just passed top center on the firing stroke, the ratchet releases the spring. All the energy stored in the spring is then used to spin the magneto at a rapid rate, thus producing a hot spark in the cylinder which is on the firing stroke. As soon as the engine begins to run, centrifugal force engages a pawl inside of the coupling which renders the spring and ratchet mechanism inoperative, so that the magneto functions just as it would without the impulse coupling. It is obvious that a magneto so equipped cannot be timed in the customary manner, since at slow crankshaft speeds it does not turn with the crankshaft. The following instructions are given by the Scintilla Magneto Company for timing and synchronizing the SB6R-2 magneto equipped with an impulse coupling:

"Remove the impulse coupling cover after taking out the two securing screws which hold the coupling cover halves together. In order to remove the top half of the cover it will be necessary to rotate it until the end clears the large hexagon nut in the front end plate which secures the distributor gear axle. MAKE SURE THAT THE FELT RETAINING RING IS LEFT ON THE BODY OF THE IMPULSE COUPLING or placed over the drive member on the engine before installing the magneto on the engine.

"Rotate the magneto drive shaft in the direction OPPOSITE to the RUNNING ROTATION of the magneto (indicated by the arrow on the magneto cover) until the timing mark "A" on the chamfered tooth of the gear (Fig. IV), and the timing pointer "B" are opposite each other as seen through the timing window in the magneto cover. At this position the breaker contacts should begin to open. (The drive shaft is turned in the direction opposite to running rotation in order that the impulse coupling will not engage. Another method is to turn it in the direction of running rotation and then disengage the coupling as explained below.)

"When synchronizing the magnetos after they are installed, the impulse coupling on the one magneto will engage when the engine crankshaft is turned in the direction of normal rotation, thereby preventing the rotating magnet and breaker cam from turning for the opening of the contact points. To prevent this the coupling must be disengaged by depressing the pawl with the finger at point "A", as shown in Fig. V. With the impulse disengaged, the coupling will operate as a plain drive coupling, thereby allowing the rotating magnet and breaker cam to turn in the normal manner. The pawls will engage two times for each revolution of the magneto drive shaft and must be disengaged each time by hand while the magnetos are being synchronized.

"After the magnetos have been synchronized, the impulse

coupling cover can be reinstalled. Place the coupling cover half which is stamped 'E 30 R' on the top side. The felt retaining ring, which was placed on the body of the impulse coupling or over the

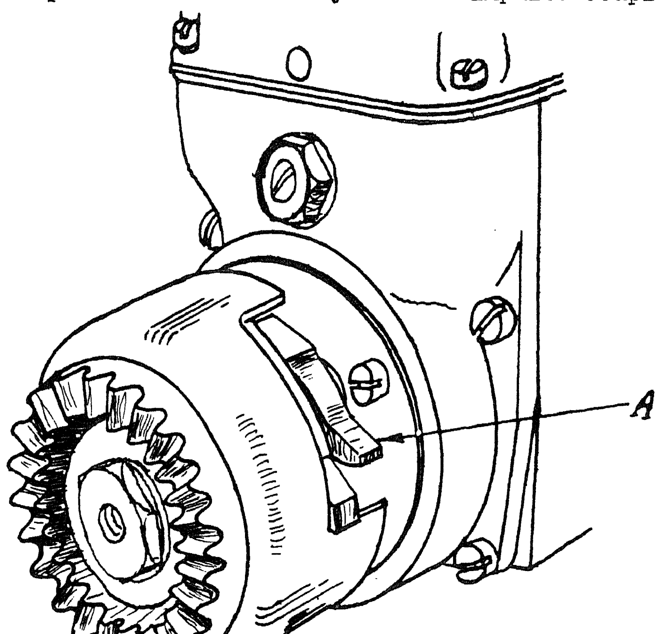


FIG. V

drive member on the engine before the magneto was installed, must be placed in correct position on the coupling housing so that it fits in the groove provided in the coupling cover halves. After the cover halves are placed in position, they must be secured with their two screws.

"The 'E 30 R' stamped on one of the coupling cover halves indicates that the coupling is the 'E' type, having a lag angle of 30° for 'Right Hand', or clockwise, rotation, as viewed from the drive end. The lag angle of 30° means that the spark is automatically retarded 30° for starting purposes during the time the impulse coupling is engaging. When the engine has attained proper speed after starting, the impulse coupling will automatically disengage and operate as a plain drive coupling."

MAINTENANCE OF MAGNETOS

Scintilla magnetos require very little maintenance. The Scintilla Company makes the following recommendation with respect to the care of the AG and V-AG magnetos:

"Each magneto has two oil holes, one at the top of the front end plate and another at the breaker end of the main cover. These are for supplying oil to the two ball-bearings of the rotating magnet shaft. Each oil hole is protected by a hinged aluminum cover.

The distributor gear bearing on V-AG magnetos is packed in grease and consequently requires no lubrication while in service. It must be packed with Keystone grease No. 44 or the equivalent when the magneto is overhauled. On AG magnetos the distributor gear bearing is supplied with oil from the front end plate oil hole.

"The magneto should be oiled when first installed, with the best available grade of medium bodied lubricating oil and thereafter regularly at the end of every 25 flying hours. At this interval put a generous amount into the front end plate oiler, as any excess will drain away through holes in the magneto base. The rear (breaker) end oiler should receive 5 to 8 drops, as over-oiling at the end may interfere with magneto operation if it reaches the breaker contacts. See that the felt wick in the bottom of the breaker cage is saturated with a heavy bodied lubricating oil."

Inspection and adjustment of breaker points will be discussed later.

With respect to the SC magnetos, the following recommendations are made by the manufacturer:

"The Gits oiler projecting from the magneto housing near the top lubricates the upper main bearing. After every 20 flying hours fill this with the proper oil. (Oil, lubricating, aircraft engine, grade 98. U. S. Army Air Corps Specification 3556.) This oil insures that the lubricant with which the upper and lower ball bearings are packed, (Grease, high melting point, grade 295 [soft, medium] U. S. Army Air Corps Specification 3560) will remain soft. These bearings are to be repacked with grease at each overhaul.

"If lubricants of the foregoing specifications are not available, use a medium bodied mineral lubricating oil of best available grade and a light grease such as Keystone No. 44 or the equivalent. For hot weather or tropical conditions it may sometimes be advisable to use a heavy bodied lubricating oil.

"The felt lubricators attached to the breaker cam followers should be moistened with the same oil when inspection, made at monthly or at directed intervals, shows that they are becoming dry. <u>Do not permit oil to drip from the felt lubricators or to touch the breaker contacts.</u>"

The SB, SF, and Bendix magnetos are greased only at overhaul except that the lubricating felt in the breaker assembly of the Bendix models must be kept damp with oil. This will be discussed in more detail later.

<u>CHECKING AND ADJUSTING BREAKER ASSEMBLY</u>

At the time of periodic checks the breaker assembly should be inspected. The utmost care should be used in this work, since any sort of trouble with the breaker points may result in a weak spark, or no spark at all. The procedure varies with the different types of magnetos. The more common models will be discussed below.

<u>Checking AG Breaker Assembly</u> - An enlarged view of the breaker

points of the Scintilla AG and V-AG is shown in Fig. I, and a Scintilla wrench, equipped with .012" feeler gage in Fig. II. The procedure in checking is as follows:

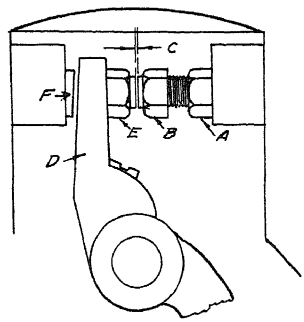


FIG. I

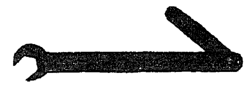


FIG. II

1. Wipe the magneto clean.

2. Remove the safety pins and lift off the breaker box cover.

3. Inspect the contact surfaces at the points to see that they are clean and that they seat evenly over their entire face. If there are any mounds or pits on the points, loosen lock-nut "A" and screw point "B" in far enough to allow point "E" to be unscrewed and removed. Then remove point "B". The faces of the points should now be trued on an oilstone until they are perfectly smooth. Only an expert mechanic should attempt this work.

4. If the points are in good condition, open the points by rotating the magneto by turning the propeller in the direction of its normal rotation. If the magneto is on the bench, turn the drive shaft by hand.

5. When the breaker arm has reached the limit of its normal movement try a .012" feeler gage between the edges of the points (dimension "C" in Fig. I).

6. If the dimension is not correct loosen the lock nut "A" and unscrew point "B" to decrease the clearance, or screw it in to increase the clearance. CAUTION: The breaker arm "D" can be sprung further open than its normal movement. Accordingly, care should be taken that the feeler gage does not fit too tightly, as otherwise the clearance will be too little.

7. When the clearance has been adjusted to .012", tighten the locknut. CAUTION: Since the threads are delicate, care should be taken not to tighten the locknuts enough to strip them.

8. Check clearance between the back and the breaker arms and the fibre stop when the points are fully opened. This clearance should be from .002" to .010".

9. Recheck the gap clearance by rotating the magneto until the points break again, and again inserting the feeler gage.

10. If the magneto is on the bench, the internal timing should be checked by turning the drive shaft until the timing mark on the edges of the distributor gear and on the front end plate are in

line as previously described. With the gear in this position, the point should be just beginning to break. This can be determined by the use of cellophane, as described in the section devoted to timing and synchronizing the magnetos.

11. Put a few drops of medium oil on the oil wick on the breaker cam, but be careful that no oil gets on the breaker points.

12. Replace the breaker box cover and the safety pins.

Checking Breaker Assembly on V-AG-D3 Magnetos - V-AG magnetos whose type designations terminate with "V3" have a pivotless breaker similar to those used in the SC, SB, and other later models. See Fig. III. No clearance adjustment is necessary between contact points. At periods of regular engine checks, but not exceeding fifty hours of service; remove the breaker cover and check the adjustment of the breakers as described below. At the same time check the felt lubricator attached to the cam follower and apply a few drops of oil if necessary. This lubricator should not become dry, but on the other hand oil must not be permitted to drip from it or touch the breaker point.

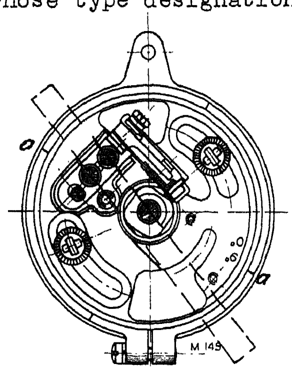


Fig III

The following inspection and adjustment instructions are supplied through the courtesy of the Scintilla Magneto Company:

"The contact breaker cover is removable when the two cover thumb screws are loosened. This cover contains two ventilating screens which prevent the entrance of water or the egress of flame in case any combustible vapor in the breaker housing is ignited from a spark.

"The breaker mechanism is held in place by two hold-down springs. When these are removed, the breaker can be withdrawn from the magneto.

"Make sure all rivets and screws in breaker and housing are tight and that faces of contacts are clean and smooth. Wipe breaker housing clean if necessary with an oily cloth. Polish away any projecting points on contact faces if necessary and check tension of breaker main spring, using Scintilla Tension Gage 4-2194. (See Fig. IV.) The spring tension must not fall below 10 ounces, the lowest permissible limit.

"The breaker main spring is secured to the breaker support by a screw and nut. The clearance between the contact spring and the cam follower should be between .045" and .075". These clearances are important to insure that the cam follower follows the cam contour and thus prevents chattering or vibration of the contact main spring.

"It is possible to disassemble the breaker (rivet-type breakers excepted) to permit replacement of worn or broken parts.

"If the contact spring pressure, as checked by gage, is too low it can be raised by the removal of a washer, Part No. 10-3768 (see Fig. IV). If too high, it can be lowered by inserting an additional washer part No. 10-3768. It is recommended, however, that when these breakers require replacement of parts they be returned to the manufacturer for repair and retest.

"The insulated primary segment on the back of the breaker housing must be clean and smooth. See that the laminated primary brush attached to the coil is in good condition and touches this pad when the breaker housing is approximately 1/16" out from its normal position in the magneto housing. The tension of the hold-down springs should be 15 to 30 lbs. -- preferably about 23 lbs.

"When reassembling breaker into magneto, apply a little light oil to the pilot diameter of the breaker housing and to the insulated pad on back of housing to insure easy movement. Place breaker housing in magneto housing, being careful that cam does not injure cam follower when breaker is pushed into place. Secure hold-down springs.

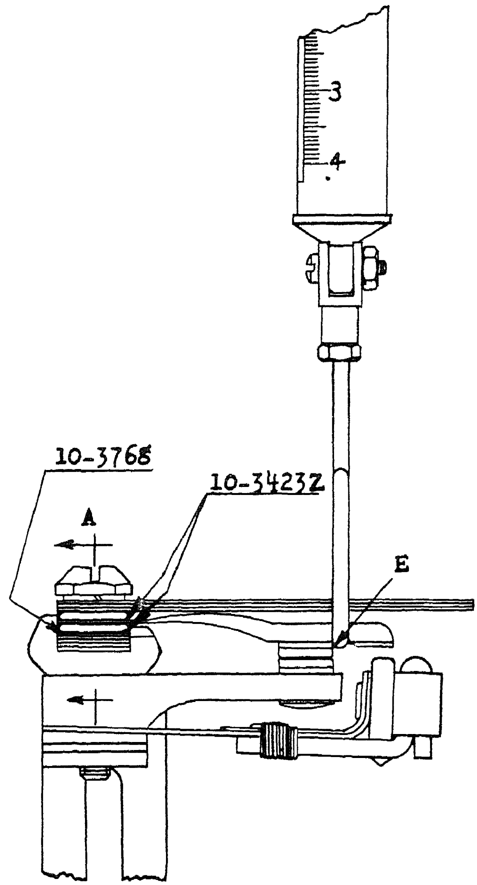


FIG. IV

"With breaker in full advance position, place a straight edge such as a steel scale against the face of the step cut in top of cam. (Indicated by dotted line in Fig. III.) Turn magneto drive shaft until this edge coincides with the lines (a - a) cut opposite each other on the rim of the breaker housing. Loosen the two screws which fasten the breaker support to the breaker housing and adjust by means of eccentric at end of breaker support until contacts are at instant of opening. Secure breaker support in this position by tightening fastening screws. The opening of the contacts can be conveniently checked with cellophane."

<u>Checking Breaker Assembly on Model DF Scintilla Magnetos</u> - The Scintilla Company makes the following recommendations with respect

to the inspection of the contact breakers on the type DF magnetos:

"When inspecting the contact points, the breaker main spring should not be raised beyond the point giving 1/16" clearance between the movable and stationary contact points. Further tension of the main spring caused by raising it beyond this point will result in the weakening of the main spring.

"Check the main spring tension with Scintilla Gage No. 4-9713. It is important that the hook of the gauge be applied on the main spring adjacent to the contact point as illustrated at 'E' (Fig. IV.)

"Main springs that have been in service and have a tension of not less than 10 ounces will be satisfactory for further service.

"New main springs should have a tension of 20 to 32 ounces.

"If the main spring tension as checked by Scintilla Gage No. 4-9713 is too low, it can be raised by removing washer No. 10-3768 (Fig. IV). If it is too high, it can be lowered by inserting an additional washer No. 10-3768. The other function of washer No. 10-3768 is to obtain maximum contacting surface between the contact points.

"Examine the contact points for evidence indicating excessive wear. Mounds or peaks appearing on the contact surfaces should be removed. It is not considered necessary to remove slight pits which appear on the contact surfaces unless they are in excess of 10% of the total contact area. Dressing of the contacts should be undertaken only by the most experienced operator and can be accomplished by using the Scintilla dressing tool No. 4-12176 and the Scintilla special cut file No. 4-12177 and stone No. 4-12868.

"Normal operation of the magneto causes a certain amount of wear to take place on the top of the cam follower. This wear is indicated by a small depression worn in the top of the cam follower at the point where it lifts against the end of the main spring. The distance between the lowest point of this depression and the top of the spring on which the cam follower is riveted should be checked at each overhaul. This distance should be 1/32" or over. If it is less than 1/32", a new cam follower should be installed.

"If the above inspection indicates that the contact breaker assembly requires replacement of parts, it is highly recommended that reference be made to Scintilla Service Bulletin No. 40."

"It is assumed that the contact breaker is completely assembled after its having been inspected as directed in the section entitled 'Inspection after Disassembly'.

"Install the contact breaker assembly in the housing and secure it with the two breaker hold-down springs. For fixed spark requirements, insure that the breaker stop collet engages the bushing provided for it in the breaker housing. The breaker stop collet is inserted in the hole marked 'Fixed R' or 'Fixed L' for fixed spark

requirements, clockwise and anti-clockwise rotation, respectively.

> "IMPORTANT: Scintilla pivotless type contact breakers as used in these series magnetos must always be adjusted so that the contacts open at the proper position of the breaker cam in relation to the timing marks in the rim of the breaker cup and not for any fixed clearance between the contacts.

"Apply a few drops of standard grade oil on the cam follower felts. After application, remove any excess oil with a clean, dry cloth.

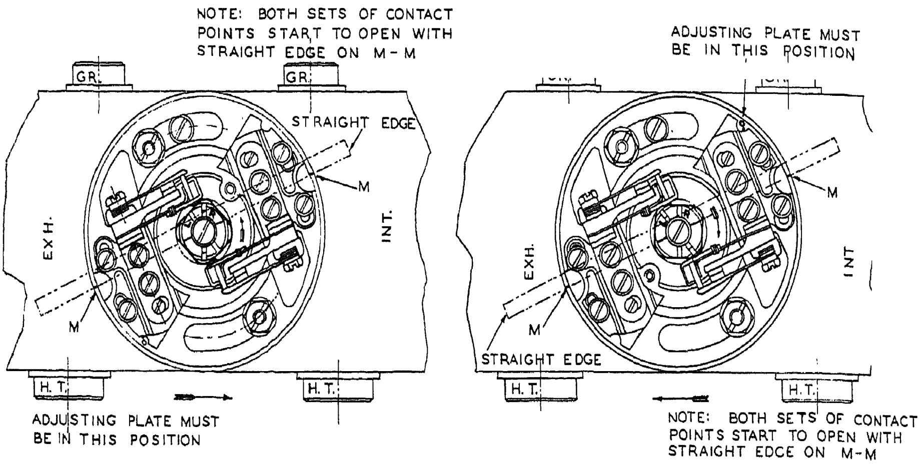
"Adjustment for Synchronized Sparks, Either Rotation - The contact breaker assemblies are mounted on adjustable plates. There are three engraved marks '0°', '4-1/2°', and '9°', on the base of the breaker housing under one of the adjusting plates. The other adjusting plate has no engraved marks under it and is fixed in one position by its two securing screws. The adjusting plate which is over the engraved marks should be fixed so that the '0°' mark can be seen through the center of its recess.

"With the breaker in full advance position and the adjusting plates in the position as described above, place a straight edge against the face of the step cut in the adjustable cam cap (Figs. V and VI). The mark engraved 'R' on the adjustable cap engages the projection of the cam for clockwise rotation and 'L' for anti-clockwise rotation. Turn the magneto drive shaft until the straight edge coincides with the timing marks 'M' on the rim of the breaker cup. Loosen the two fastening screws of each breaker assembly and adjust the eccentric screw so that the contact points just begin to open. When the adjustment has been made, tighten the screws securely. The opening of the contacts can be checked conveniently with a strip of very thin cellophane between the points. When the cellophane is released with a slight pull, the contact points are just beginning to open. Insure that pieces of cellophane are not left between the points when adjustment has been made. Recheck the adjustment after having tightened the securing screws of the contact assemblies.

"Adjustment for Staggered Sparks - Clockwise Rotation - (4-1/2° Staggered Sparks). Move the adjusting plate which is over the engraved marks so that the 4-1/2° mark can be seen through the center of the recess (Fig. VII). The fixed assembly contact points should open when the straight edge coincides with the timing marks 'M' on the rim of the breaker cup. The 4-1/2° staggered assembly contact points should open at a position 4-1/2° earlier. It is recommended to place a mark on the post of the adjusting plate opposite the timing mark 'M' when the '0°' mark shows in the recess. When the adjusting plate is moved to its staggered position, the contact points of the staggered side should open when the straight edge coincides with this mark.

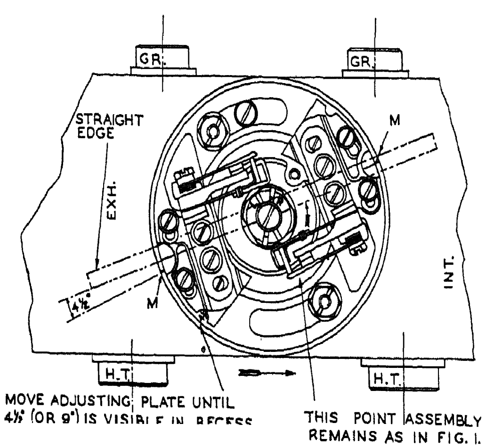
"(9° Staggered Sparks) - Move the adjusting plate until the 9° mark is visible through the center of its recess. Proceed as explained under the '4-1/2° Staggered Sparks' above.

"Adjustment for Staggered Sparks - Anti-clockwise Rotation - Adjustment for '4-1/2°' and '9°' staggered sparks is accomplished in the same manner as explained under 'Adjustment for Staggered Sparks- Clockwise Rotation' (See Fig. VIII)."



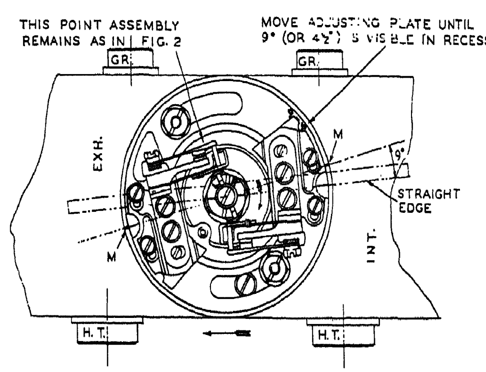
SYNCHRONIZED SPARK - CLOCKWISE ROTATION   SYNCHRONIZED SPARK - ANTICLOCKWISE ROTATION

FIG. VI



STAGGERED SPARK - CLOCKWISE ROTATION

FIG. VII



STAGGERED SPARK - ANTICLOCKWISE ROTATION

FIG. VIII

Checking Breaker Assembly on Model SB and SF Magnetos - The procedure in inspecting the breaker points, checking the spring tension, etc., is identical with that followed in the case of the type DF just discussed. It should be remembered that in the case of these and all other magnetos with the pivotless breaker points there is no adjustment for clearance and any change is almost certain to throw the magneto badly out of time, with the resulting danger of loss of power and fire hazard in starting. To check the internal timing of the magneto, or the point at which the contacts open with respect to the position of the distributor, the Wright Aeronautical Corporation makes the following recommendations, which were prepared with the approval of the Scintilla Company:

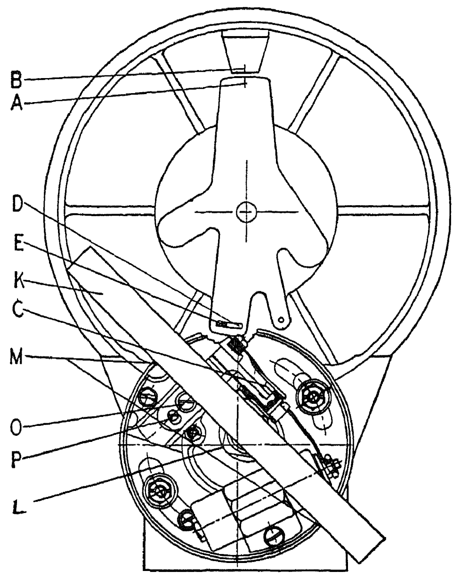


FIG. IX

"Whenever a breaker has to be adjusted in service it should be wiped but with a clean cloth moistened with gasoline. When doing this, do not permit gasoline to come in contact with the cam follower or the follower felt. Gasoline on these would remove the glaze from the follower and then the oil in the felt. To check the contact breaker adjustment turn the magneto drive shaft until the timing mark 'A' (See Fig. IX) provided on the distributor finger lines up with the corresponding mark 'B' on magneto front end plate. The distributor rotor is now in position to distribute a spark to the distributor block electrode 'E' of cylinder No. 1.

"Place a straight edge, preferably a steel scale, 'K', against the face of the step cut in the cam 'L'. Turn magneto drive shaft slightly until this straight edge coincides with the lines 'M' cut in the rim of the breaker housing. In this position the breaker contacts should be just opening.

"Pivotless breakers must always be adjusted so that the contacts open at the proper position of the cam and not for any fixed clearance between the contacts as is the case with lever type contact breakers.

"If inspection shows that the position of opening of the contacts requires adjustment, loosen the two screws 'O', which fasten the breaker support to the breaker housing. Hold the cam in position to open the contacts as indicated by the straight edge and adjust by means of the eccentric 'P' until the contacts are just opening. Secure them in this relation by tightening the screws 'O'."

"The position of opening can be most conveniently checked by placing a piece of .001 inch steel feeler stock between the contacts and pulling against it lightly. When the feeler slips the contacts are opening. The position of opening can also be checked with a lamp and battery, in which case a piece of thin insulating material must be placed between the primary contact brush of the coil and the back of the breaker housing to prevent battery current from flowing through the coil.

"Owing to the wear of the cam follower, it may be found necessary to adjust the eccentric 'P' to its maximum position to permit the cam follower to lift the main spring and movable contact points at the instant the straight edge coincides with the timing marks. If this relation can be obtained, the cam follower is satisfactory for further service. However, during major overhaul, if, after having adjusted eccentric 'P' to its maximum position, it is found that the straight edge 'K' slightly passes the timing mark 'M' (as drive shaft is turned in direction of the rotation of the magneto) before the contact points begin to open, it will be necessary to install a new cam follower. During periodical inspections made between major overhaul periods an allowance of 1/8" between the timing mark on the rim of the breaker cup and straight edge is permissible."

Checking Breaker Assembly on Bendix Magnetos - The breaker assembly used on these magnetos is different from those on the preceding type, as will be seen by referring to Fig. X.

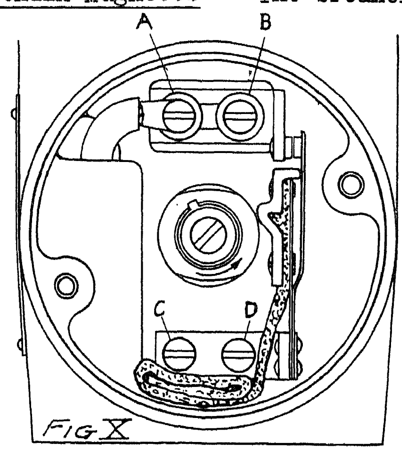


FIG X

The Scintilla Company makes the following recommendations with respect to the adjustment of the contact points so far as the internal timing of the magneto is concerned:

"1. Turn the drive shaft until the mark 'A' (See Fig. IV in preceding section on 'Timing and Synchronizing') on the camfered tooth of the large distributor gear is opposite the timing pointer 'B' inside the magneto cover as seen through the window. When these two marks are opposite each other, the breaker contacts should be just opening. A convenient way of checking this adjustment is to place a piece of thin cellophane between the contacts and pull against it slightly. When the tissue slips, the contacts are separating. Insure that particles of the cellophane are not left on the contact points after the adjustment has been made.

"2. If the contacts do not open at the proper time, loosen the two screws, 'A' and 'B' (Fig. X), which hold the stationary contact assembly in place and move the stationary contact to right or left until the two contacts separate when the timing marks are opposite each other. It should be noted that the contact points are not adjusted for any fixed clearance between them.

"3. If the contacts do not line up properly, the location of the moving contact can be adjusted by loosening the two screws, 'C' and 'D' (Fig. X), which secure the moving contact assembly to the housing. The screw holes are slightly elongated to permit this adjustment. After retightening the screws, recheck this adjustment to insure that it is correct.

"4. Insure that the lubricating felt attached to the cam follower is soft and moist with oil. This felt supplies a very minute quantity of lubricant to the breaker cam. If oil appears on the surface when the felt is squeezed between the fingers, do not add any more oil. If the felt is dry, however, moisten with a few drops of medium bodied mineral lubricating oil, preferably SAE 30. Do NOT give it all it will hold.

"Before replacing the breaker, wipe out any dirt or excess oil which may have entered into the breaker compartment during adjustment."

BOOSTER MAGNETOS AND COILS

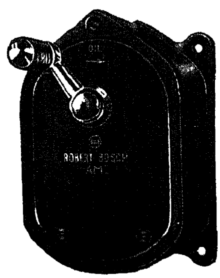
It is perhaps unfortunate that the expression "booster" was ever applied to the devices described below, since the name implies that the purpose of the so-called "booster" is to intensify the spark produced by the magneto. This is definitely not the case, for the spark produced by the booster magneto or coil has nothing whatever to do with the spark produced by the regular engine magneto and, in fact, does not even pass from the same terminal on the distributor rotor. The booster simply uses the ignition wires which run from the main magneto to the spark plug for the delivery of its spark. Realizing the inaccuracy of this term most engine manufacturers use the expression "hand starting" magnetos for the magneto type of "booster" and "starting coil" for the battery type.

As previously explained, the spark produced by a magneto varies in intensity with the speed at which the magneto is turning. When the engine is being started, either by hand or by a starter, the speed of the magneto is necessarily low and the spark, accordingly, weak. While this spark is strong enough to start the engine under favorable conditions, in cold weather or when, for some reason, starting is difficult, a booster is a valuable accessory, since it is operated by hand and the spark it produces is not affected in any way by the speed of the engine.

Referring to Fig. II, at the beginning of this Chapter, and the accompanying explanation, it will be noted that the electrode from which the booster current is discharged into the spark plug wire (the electrode shown in light lines in the end view to the left of the illustration) lines up with the wire after the electrode from the main magneto has passed by the contact point, which means that the spark produced by the booster occurs in the cylinder considerably later than the spark produced by the magneto. The reason for this arrangement is to prevent the engine from "kicking back" or beginning to run backwards when it is being started. The regular spark occurs when the piston is 25° - 30° before top center, whereas the spark from the booster occurs just after the piston has passed top center. It is essential that this be the case for, as explained

in the chapter on engine operation, the booster is often operated while the propeller is entirely stationary. Obviously, if the spark produced by the booster under such conditions occurred before the piston had reached top center, the piston would be driven backwards instead of ahead and the whole purpose of the device would be lost.

Magneto Boosters and Their Installation - There are several makes of booster, or hand-starting magnetos. The operation of all of these is practically identical and consists of simply turning a hand crank which is geared to a high-tension magneto. By means of a large gear on the crank handle and a small gear on the magneto shaft, the shaft can be spun quite rapidly, thus producing a hot spark. One type of booster magneto is illustrated in Fig. I.



Courtesy Air Associates, Inc.

FIG. I

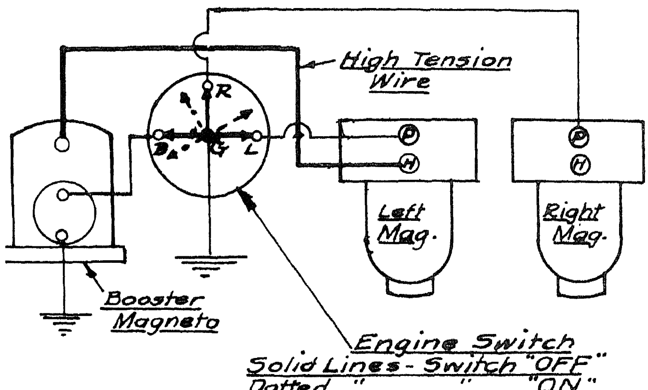


FIG. II

A diagram of the booster installation is given in Fig. II. In the diagram shown, the booster is provided with a primary connection which leads to the ignition switch, another primary connection which leads to the ground and a secondary, or high-tension connection which leads to the terminal on the magneto marked "H". Some boosters do not have a connection for the ground, but are grounded through the base of the magneto. If a ground wire is carried from one of the latter type to the engine, the wire must be attached under one of the bolts which mount the magneto. If the ignition switch is grounded to the frame of the fuselage, the booster may also be grounded in the same manner, but if the ground wire from the switch is carried back to the engine (See section on "Installation of Magnetos"), the ground wire from the booster must also be carried to the engine or else spliced into the switch ground wire. The high-tension terminal on the booster can usually be distinguished by its size, but if there is any doubt, the question may be settled very easily by passing a wire to the terminal in question, holding the other end of the wire about 3/16" away from the base of the magneto and turning the crank. If the wire is attached to the high-tension terminal, the spark will be very evident.

While the booster magneto will function without being connected to the ignition switch, from the standpoint of safety it should be so connected. Since the booster is mounted in the cockpit, at some

location convenient to the pilot, there is always the possibility that the handle will be accidentally turned by someone climbing in or out of the cockpit or in some other manner. In this event, if there should happen to be a charge in the cylinders of the engine, and the booster were not connected to the ignition switch, the engine would fire whether the switch were on or off. By connecting the booster in the manner shown in Fig. II, no spark can be produced by it when the ignition switch is in the "OFF" position. Fig. II also illustrates the other contacts in the switch when it is in the "OFF" position. It will be noted that the primary circuit of each magneto is closed or "grounded." It has been brought out before that magnetos are rendered inoperative by closing the primary circuit, but the point is emphasized here because this fact is often not fully appreciated, particularly by beginners. Also, attention is called to the point that a switch intended for use with a booster magneto cannot be used with the battery type of booster, since in the battery booster the primary circuit must be disconnected, or open, when the switch is in the "OFF" position.

The booster is connected to only one of the main magnetos, since an adequate spark in one plug should be sufficient to start the engine and the higher efficiency of operation produced by two plugs is not of great importance in starting.

When using the booster in starting the engine, the cranking should be continued until the engine is running smoothly and has picked up enough speed to cause the main magnetos to deliver satisfactory sparks.

Battery Boosters and Coils - The battery type booster functions, so far as the engine and main magneto is concerned, in the same manner as the magneto type. It has the advantage of requiring no cranking, since it is operated merely by pressing a button. Also, if the ship carries a battery for radio, starting, lighting, or other purposes, there is a considerable saving in weight by using this type, since the coil weighs much less than the booster magneto. The current may be supplied either from the regular storage battery, as just mentioned, from conventional dry cells of the "hot-shot" type, or from radio B-batteries. Booster coils may be obtained in several types, one of which is shown in Fig. III. The coil is mounted in any convenient location, likewise the battery. The only part of the system which needs to be within easy reach of the pilot is the push-button. This push-button is a necessary part of the system, since otherwise the booster would function continuously while the ignition switch were on. This would not interfere with the running of the engine since the spark from the booster occurs after the spark from the main magneto, but it would constitude an unnecessary drain on the battery.

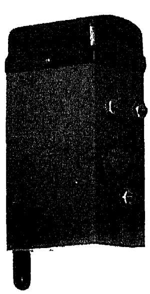


FIG. III

Fig. IV is a diagram of the electrical hook-up of the battery and coil booster. The coil is provided with one secondary and two primary terminals, connected as shown in the diagram. It should be noted that when the ignition switch is in the "OFF" position, the

primary circuit of the coil is open, while the primary circuit of the main magneto is closed. The connection from the high-tension terminal of the coil is of high-tension cable and runs to the terminal of the magneto marked "H". Some mechanics do not carry the primary circuit through the ignition switch, feeling that the push-button constitutes enough of a safety precaution; however, it is a much better practice to make the connection as indicated in the diagram.

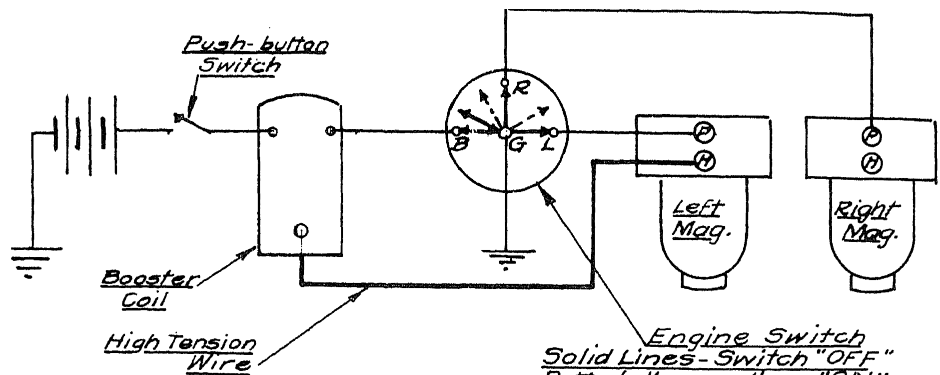


FIG. IV

BATTERY IGNITION

As optional equipment many of the smaller engines offer battery ignition. The advantages, which have been previously discussed, consist chiefly of a better spark for starting and lower weight, provided the battery is carried for other electrical equipment. One of the first modern aircraft engines to use battery ignition was the Jacobs and since the ignition installation on this engine is typical, it will be used as the basis for the instructions in the following paragraphs. The type most commonly used is manufactured by the Scintilla Magneto Co. through whose courtesy the illustrations and explanations below are supplied.

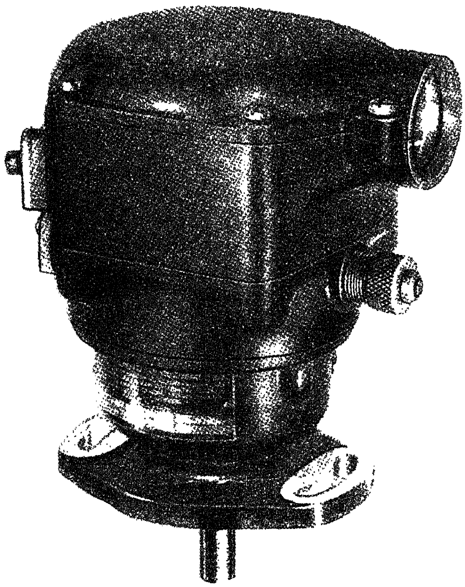


FIG. I

The Bendix Scintilla Battery Ignition Equipment - This equipment as supplied on the Jacobs Aircraft engines consists of two timer distributors and two coils, thus supplying complete dual ignition. Each timer distributor is provided with an automatic advance governor and consequently no manual spark advance is needed. The timer distributors and coils are radio-shielded, and are provided with terminal connections for the installation of standard radio-shielded cables. Fig. I shows the Scintilla type WL-7a timer distributor and Fig. II shows a coil. Since both of the timer distributors run at one-half engine crankshaft speed (thus providing sparks in each cylinder every other revolution), the one marked 15° corresponds to an advance range of 30° on the engine and the one marked 8° corresponds to 16° on the engine. At flying speed, both fire fully advanced at 30° before the top dead center position of the piston. Consequently, the "15°" timer distributor is set to spark fully retarded when the piston is on top dead center, when the engine is running slowly, and the "8°" timer distributor is set to fire fully retarded at 14° before top dead center, under the same condition.

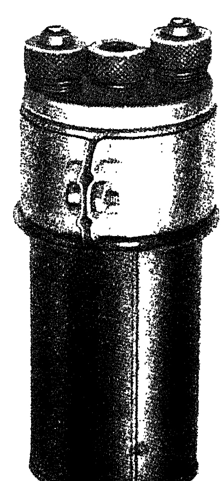


FIG. II

This method of timing provides a fully advanced spark on both timer distributors at flying speeds. In starting the engine, the switch is turned to the position ("L" or "R" on the switch) at which only the "15°" timer distributor

is fired. This gives a fully retarded spark, occurring at top dead center for starting. The "8°" timer distributor is sufficiently advanced to permit quick acceleration when the engine is idling.

Installing and Timing - A wiring diagram of the entire system is shown in Fig. III. Anyone familiar with the wiring of an automobile electric system should have little difficulty understanding this one.

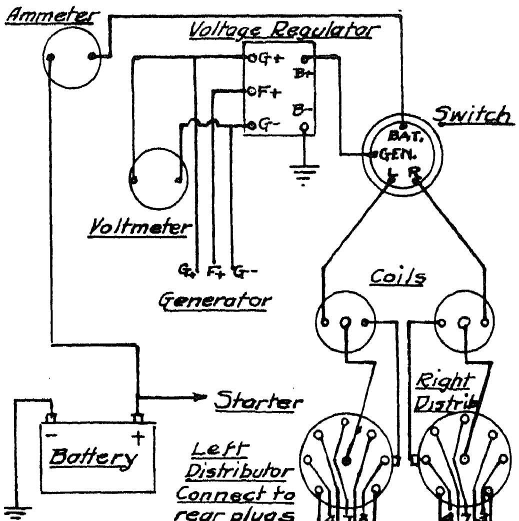


Fig III

Kindness of Walter Kupchak

To time the distributors to the engine, the crankshaft is turned until the piston of No. 1 cylinder is on top center on its compression stroke, as determined by a timing disc or a timing pointer of some type. The distributor heads are removed and the timer distributor marked 15° is installed with the distributor finger approximately opposite the position of No. 1 electrode. The timer distributor can be rotated after it is mounted through the range provided by the slots for the mounting studs in the base or flange of the unit. With the piston on top center the timer distributor should be rotated until the contact points just begin to open. This opening may be checked with a piece of cellophane in exactly the same manner as has been discussed in the section devoted to magnetos. If additional movement is necessary, it may be secured by loosening the screws, M, M, M, in Fig. IV, which shows the breaker assembly. The nuts which secure the timer distributor to the mounting studs should be tightened when the unit is set in the position at which the contact points just begin to open.

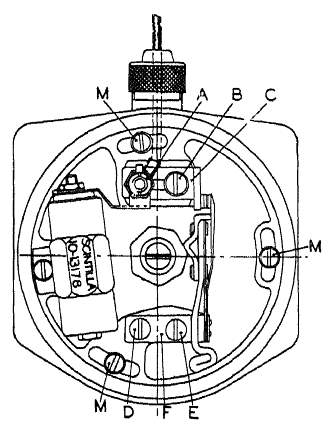


Fig. IV

Having installed the "15°" timer distributor, turn the engine crank shaft slightly less than two revolutions ahead until the piston of No. 1 cylinder is 14° before top dead center on its compression stroke. The timer distributor marked 8° should then be installed in the same manner as explained for the "15°" unit.

Maintenance - At intervals of approximately 100 hours, each distributor head should be removed and the lubricating felt which is

attached to the cam follower examined. If it is dry, it should be oiled with two drops of medium lubricating oil. Great care should be taken to see that no oil ever reaches the breaker points since pitting and burning of the points and possible failure of the entire timer distributor might result.

After examining the felts the breaker points should be checked as follows: Beginning with the timer distributor marked 15°, the engine crankshaft should be turned so that the clearance between the contact points is at a maximum. This clearance, measured with a feeler gage, should be from .014" to .018". If adjustment for clearance is necessary, the two screws A and B (Fig. IV) which hold the contact point assembly, C, in place should be loosened. This contact point assembly may then be moved to the right or left until the desired clearance of .016" is obtained, after which the screws A and B are tightened. Vertical alignment of the points may be obtained by loosening the two screws D and E and moving the contact point assembly, F, to the desired position.

After the proper clearance has been obtained, the crank shaft should be turned until the piston of No. 1 cylinder is on top center on the compression stroke. The three screws, M, M, M, should then be loosened and entire breaker housing assembly moved until the contact points just begin to open, as checked by cellophane in the customary manner. At this position, the distributor finger should be just opposite the No. 1 electrode of the distributor head. The screws, M, M, M, should be tightened after adjustment is made. If necessary, the two mounting flange retaining nuts may be loosened and the entire unit rotated through the range provided by the slots in the mounting flange.

Having adjusted the "15°" timer distributor, the other may be checked in the same manner except that when making the adjustment in the contact point opening, the crankshaft should be turned until the piston of No. 1 cylinder is at a position 14° before top dead center on the compression stroke.

As a part of this periodic inspection, the carbon brush in the distributor head and the contact spring on the distributor finger should be examined for wear. The distributor finger can be readily removed with an upward pressure applied by <u>the hand alone</u>. Under no circumstances should a screw driver or similar tool be used for prying off the distributor finger.

<u>INSTALLATION AND CARE OF BATTERIES</u>

The principles of the storage battery and the details of its construction have been previously discussed in the chapter devoted to the Principles of Electricity. The installation and care of the battery while in use will be covered in the following paragraphs. The instructions and illustrations in this section are supplied through the courtesy of the Electric Storage Battery Co., manufacturers of "Exide Aircraft Batteries", one of the most popular types.

<u>Installation</u> - As a rule, aircraft batteries are shipped fully charged and with electrolyte in the cells. If they are shipped without electrolyte for any special reason, there is usually a tag

attached to the battery giving instructions for filling and charging. If, upon arrival of the battery, examination indicates that some of the electrolyte has been spilled, it should be replaced with electrolyte of the same specific gravity as that in surrounding cells. If the specific gravity is below 1.250, the battery should be given a freshening charge.

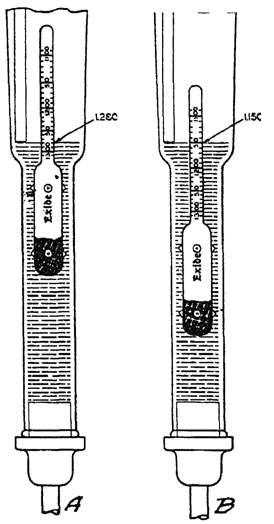
The battery compartment should be ventilated, dry and clean and should not be near the engine or any apparatus that will raise its temperature above 110° F. Its location should be accessible to permit inspection, the adding of water, and its removal for re-charge. The battery should be seated evenly and fastened down by some device which produces a snug fit but not an extremely tight fit. Too much pressure should not be applied to rubber containers. If hold-downs are used on batteries equipped with handles, they should be applied inside of the holes in the handles and not to the top of the hancles. The battery compartment should be fully protected with acid-proof paint and the container should be properly drained and ventilated.

Connecting cables must be flexible and long enough to prevent an undue pull on the battery terminals. They should be properly anchored and protected against chafing where they are in contact with parts of the structure, fire walls, and the like. It should be remembered that the positive terminals are painted red on top, are marked "POS.", or identified with a plus sign (+). The negative terminals are painted black, marked "NEG." or identified with a minus sign (-).

When attaching the cables to the terminals, the terminals and the clamps should be scraped perfectly clean. A film of No-Ox-Id or vaseline should be applied to the clean surfaces. After the clamps or nuts have been tightened, any surplus grease may be wiped off.

Maintenance - The condition of the battery should be checked at least once a week if the ship is being flown regularly, and oftener in warm weather. The routine check consists merely of adding distilled water to the cells if the level is low and of checking the specific gravity of the electrolyte. The low level point is the top of the separators and the high point the splash cover on the inside in the case of the double chamber non-spillable types, of 1/4" above the plate protector on the other types. The time of adding water during cold weather is important if the battery is not in a heated room. Under such conditions water should be added just before the engine is operated or the battery is to be otherwise charged. If water is added and the battery left without operating the generator, the water will freeze just as readily as if it were not in the battery. On the other hand, a fully charged battery will not freeze.

Nothing but distilled water should be added to storage batteries unless some of the electrolyte has been spilled. No appreciable amount of acid in the electrolyte is ever lost by evaporation. All the cells should take the same amount of water. If one consistently requires more than the others, the battery should be removed and sent to a service station for inspection, as it is probably a leak has developed. If the cells flood or sputter electrolyte, it is an



Courtesy Electric Storage Battery Co

FIG. I

indication that the level of the electrolyte is too high and should be lowered by withdrawing in the hydrometer.

The specific gravity of the battery is determined by a hydrometer, an instrument consisting of a glass tube in which is a float, and is provided with a rubber bulb on one end and a rubber tube on the other. Strictly speaking, the hydrometer is merely the float, but in common usage, the entire instrument is referred to by this term. A hydrometer reading is taken by inserting the rubber tube into the electrolyte, squeezing the bulb, releasing gradually, thereby lifting enough of the liquid into the tube to support the float. The lower the specific gravity of the electrolyte, the deeper the float will sink. The sides of the float are marked with a scale. The reading at the point where the surface of the electrolyte strikes the float is the specific gravity of the liquid. Fig. I shows the hydrometer with a reading of 1.280 in A, and 1.150 in B.

The same cell should not be used each time for taking the readings since there may be a possible loss of a small amount of electrolyte. By changing from one cell to another, this loss is spread over all the cells rather than only one. If the level of the liquid is low, it may be necessary to tilt the cells to obtain enough electrolyte to supply a satisfactory reading. The syringe must be held vertically while the reading is being taken. After the specific gravity has been noted, the electrolyte should be returned to the same cell from which it was removed. It is important that the syringe be kept clean, as a dirty hydrometer will not read accurately.

Readings should not be taken immediately after adding water since a certain amount of time is required for the fresh water to mix with the electrolyte. If the battery is not on charge, the period allowed for mixing should be at least a day. On the other hand, if the battery is being charged, an hour will suffice. Another point which should be remembered is that the temperature affects the reading. If the temperature is low, the reading will be high, and vice versa. The ideal temperature for testing is from 70° F. to 80° F. A change of 30° F. affects the specific gravity approximately 10 points, or .010.

General Instructions for Charging - It should be understood that there is little likelihood of injury to the battery as a result of its being fully discharged provided it is promptly recharged. It should also be remembered that the ampere hours which may be obtained from a battery are greater when the discharge is brought about by the use of a small amount of current for a long period of time than when it is caused by a high rate of discharge for a short period of time. In this connection, it may be well to review the

explanation of the expression "Ampere-Hour."

An ampere-hour is a current of one ampere for a period of one hour. The capacity of a battery is given in ampere-hours. This figure is the product of a number of amperes by a number of hours. For example, a 65 ampere-hour battery will produce a current of 5 amperes for 13 hours, or a current of 13 amperes for 5 hours; or, for that matter, a current of 1 ampere for 65 hours.

High discharge rates (indicated by a high reading on the ammeter), should not be confused with over-discharge. The discharge rate may be as high as the battery will put out, provided the flow of current is not continued too long. Thus, theoretically, the battery mentioned above might be called on for a current of 65 amperes for a period of less than an hour without damage. However, a battery of this size would not give quite so large an amount of current, and furthermore, it is unlikely that the customary wiring would stand such a load.

Batteries must be charged with direct current, not alternating. If only alternating current is available, a transformer, or "battery charger, as it is frequently called, must be used. The positive terminal of the battery MUST be connected with the positive side of the charging circuit; otherwise the battery may be seriously injured. The battery compartment must be ventilated, to dispose of all gas generated by charging. Furthermore, great caution should be taken to keep lighted cigarettes or open flames away from the vicinity as the gas is highly inflammable. The vent plug should be kept in the cells except when it is necessary to take specific gravity readings or to add water.

SPARK PLUGS

One of the jobs frequently assigned to the inexperienced airplane mechanic is the cleaning and overhaul of spark plugs. While this job may appear to be unimportant, such is by no means the case. The spark plug is truly the heart of the engine and if it fails to function properly, the engine will likewise fail. Because of these facts considerable space has been given to the proper overhaul of spark plugs.

The various models of spark plugs manufactured by the B. G. Corporation, of New York City, are among the most popular on the market. It is through the courtesy of this company that the following illustrations and instructions are given. While these instructions apply specifically to B. G. Plugs, they are also generally applicable to any other type of two-piece spark plugs.

In removing spark plugs from the engine or in overhauling them, it is highly desirable to use the proper tools. While wrenches of standard size will fit the various sizes of hexagons, it is much better to purchase the special wrenches from the manufacturer. Poorly fitting wrenches often damage the plugs beyond repair.

Disassembly of Plugs - The core assembly should be removed from the shell by holding the plug in a properly fitting socket, which in turn is clamped in a vise, and loosening the shell with a special double-ended wrench, as illustrated in Fig. I. If the tools shown

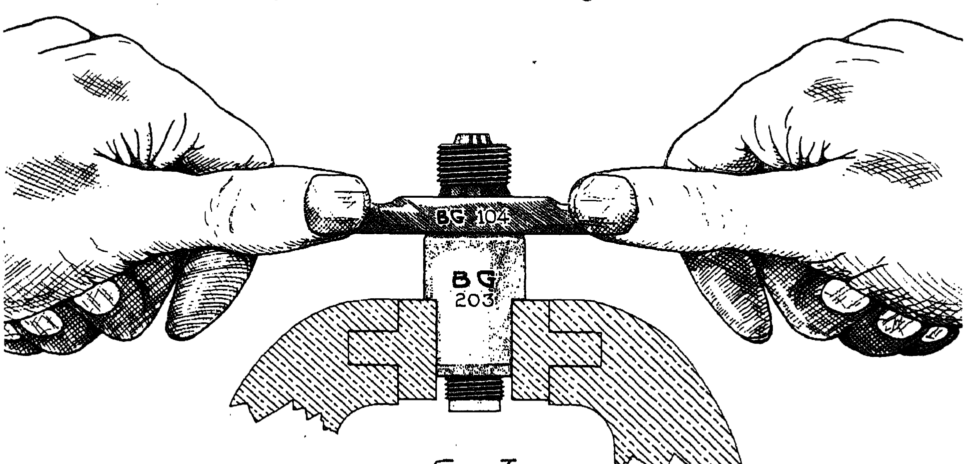


FIG. I

are not available, properly fitting socket, or box-socket wrenches should be used. Under no circumstances should the shells or cores be held directly in the vise or disassembled with open-end wrenches, for either procedure is likely to cause damage. As the cores are removed, they should be placed in holes of the proper size bored in a plank supported on blocks or legs of some sort, so as to eliminate any possibility of their being damaged or misplaced. Cores should not be placed in piles or thrown loosely in boxes. The gasket should be removed from those shells which have an internal copper gasket, by using a punch with a flat end.

Cleaning Cores - If possible, the cores should be placed in a special cleaning socket attached to an electric motor turning about 1,750 r.p.m., and cleaned with #00 sandpaper or #150 Aloxite cloth. Under no circumstances should emery or carborundum, steel wool, files, or metal buffing wheels be used to clean the cores, as chips or dust from these materials or tools will become imbedded in the mica. Such foreign matter may cause short-circuiting, resulting in spark plug failure. Care should be taken when cleaning the cores not to remove any more mica insulation than necessary, and also not to reduce the diameter of the metal electrode head next to the mica insulation. Mica spark plugs should not be cleaned by sandblasting. If no motor is available the cleaning must be done by hand, holding the core in one hand and twisting the sandpaper or Aloxite cloth back and forth around the core with the other hand.

Removing as little material as possible, the firing end of the core electrode should be smoothed to a true cylindrical shape. Otherwise, accurate setting of the gaps when the plug is assembled will be impossible. If this work is done with the assistance of the special socket and the motor, it is recommended that the sandpaper or the Aloxite cloth be tacked on a narrow strip of wood.

The core should now be washed with a brush and clean gasoline (not ethyl). In the case of shielded plugs, the inside of the barrel may be cleaned by wrapping several layers of cloth on a small wooden stick, wetting the cloth with clean gasoline or carbon tetrachloride, and swabbing the interior. Plugs or cores should never be permitted to stand in gasoline more than a few minutes, as the gasoline may carry particles of carbon between the layers of mica.

Inspection of Cores - With a micrometer, or special B. G. gage, the diameter of the electrode at the point where the mica insulation starts should be measured as shown in Fig. II. When this diameter is reduced by repeated cleaning to less than .260" the core should be rejected and scrapped. If the center electrode tip has been turned away to the extent that satisfactory gap adjustments can no longer be made, the cores should be sent back to the manufacturer so that new tips may be welded on. This becomes necessary when the diameter of the tip has been reduced to approximately .100". The exterior of the core should be dried with cloth and inspected for damage to the mica insulation and also with respect to the condition of threads, terminals and electrodes. If any of the mica is broken, flaked or dented, or if any of the laminations project beyond adjacent laminations, the core should not be used. Damaged threads may be repaired with the proper taps and dies obtained from the manufacturer or dealer.

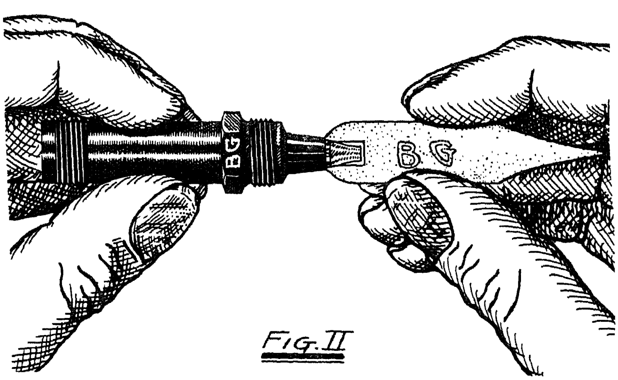


FIG. II

The threads should be lubricated with B. G. Mica Lubricant, which may be purchased from B. G. dealers, or, in emergency, with any grease which does not contain graphite. With the cores resting in the plank, electrode end up, place a new assembly gasket on each. This assembly gasket must be replaced on plugs which have an internal gasket seat every time the plug is taken apart. If the gasket is located between the top of the shell and the bottom of the coupling nut, it need not be replaced unless it shows signs of distortion or scoring.

Cleaning and Inspection of Shells - If only one or two shells are being cleaned, a stiff bristle brush and gasoline may be used. However, this is not an entirely satisfactory method, and where a large number of shells are being serviced and facilities are available, the procedure outlined below is recommended. Immerse the shells in a heated salt bath which is composed of equal parts of commercial sodium nitrate and potassium nitrate, raised to a temperature of approximately 850° F. This mixture should be melted in a cast iron or steel container. The shells should be placed in a wire mesh or perforated container, immersed in the heated bath, and left until all bubbling ceases. A considerable amount of lead will be removed from the shells in the salt bath and deposited in the bottom of the container. This lead deposit should be removed frequently. CAUTION: The shells and container must be thoroughly dry and under no circumstances should any moisture be allowed to get into the heated bath as an explosion is likely to follow.

After the carbon has been removed, as indicated by the cessation of bubbling, the container carrying the shells should be lifted out of the bath, allowed to drain for a few seconds and then dipped into hot water to remove the remaining salts. If the shells are in very bad condition they should be immersed in a 10% solution of sulphuric acid and heated to 120° F. until all corrosion or rust is removed. They should then be rinsed again in hot water. The shells should be thoroughly dried. When they are dry, if it is desired to impart an attractive finish or color, they may be immersed once more in a fresh salt bath for ten or fifteen minutes, drained for a few seconds, then washed in hot water and rinsed in clean hot water, after which they should be dipped in light oil, or a mixture of kerosene and oil, to keep them from rusting.

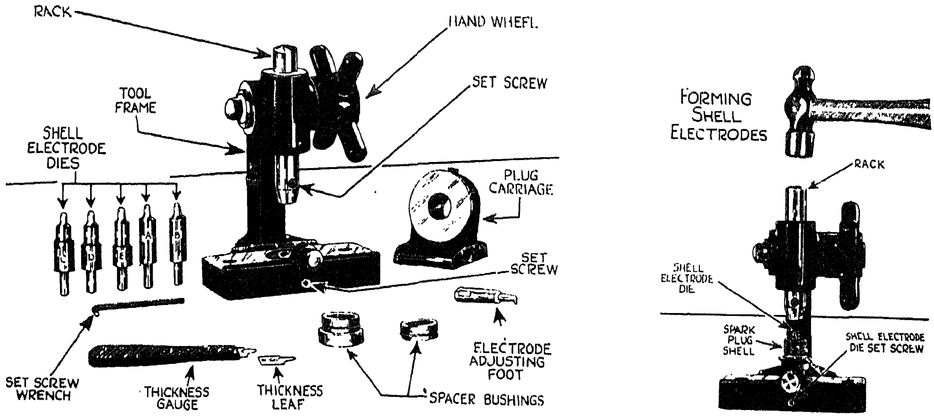
Another method of cleaning is by boiling the shells in a solution consisting of 1 lb. of Magnus No. 64 powder to one gallon of water. This powder may be purchased from the Magnus Chemical Co., of Garwood, N. J. It should never be placed in an aluminum container because of its corrosive effect, and the solution should not be allowed to come into contact with the hands or clothing. After the shells are clean, they are drained, dried with an air hose dipped in oil.

If neither of the methods outlined above can be used, the shells may be soaked in gasoline and any hard deposits removed with a knife or wire brush, care being taken that the gasket seat in the interior of the shell is not damaged.

After cleaning, shells should be inspected for damaged hexagons

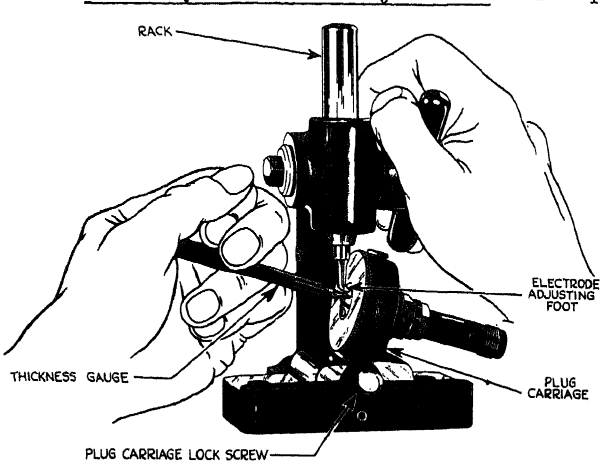
mutilated threads, etc. If the electrodes are so burned away that they can no longer be adjusted to the proper shape, the shell should be discarded. The thread may be repaired with the proper taps and dies, but every precaution should be taken to see that the diameter of the root of the thread is not changed.

If the shell electrodes are distorted, they must be re-formed by using the tool illustrated in Fig. III, which shows the B. G. Electrode Forming Tool in A, and the tool in use in B. This tool



should be a part of the equipment of every large service station. Full instructions for its operation may be obtained from the manufacturer.

<u>Assembly and Final Adjustment</u> - The plug should be assembled by means of the sockets used in disassembly. The cores are placed in the sockets and the shell tightened with the double-ended wrench previously illustrated. Excessive force in tightening should not be used, as it may damage the plug.



The electrodes may then be adjusted to the proper clearance by the use of the tool illustrated in Fig. III. Fig. IV shows its adaptation to the adjustment of the gap clearances. The gap clearance

(the space between the center electrode and the points on the shell) for the plug should be obtained from the instruction book of the engine in which it is to be used. However, the standard setting for B. G. plugs is .015". On engines of high power, the gaps may be .012" to obtain longer periods between complete plug overhaul. However, reducing the gap in this manner may cause low-power engines to idle unsatisfactorily. If the tool illustrated in Figs. III and IV is not available, the gap may be set by holding a metal rod with a rounded end on the electrode and tapping it lightly with a small hammer. The conventional feeler gage is too wide for satisfactory use in checking gap clearance. The tool illustrated in Fig. II is supplied by the B. G. Company for this purpose, the pointed end, (shown between the fingers in Fig. II) being used as the feeler gage. If no such tool is available, a standard feeler gage may be cut to a point.

Testing Plugs - Plugs should be tested to see that they spark properly. Testing the plug in the open air is of no great value, because sometimes the plugs will spark at atmospheric pressure but will not spark under the compression developed in the cylinder of the engine. Hence, it is necessary to use a testing "bomb", which is simply an air-tight compartment provided with a threaded hole for the insertion of the plug, a glass window for watching the spark, a pressure gage for indicating the pressure inside the bomb, and a hand pump, or other means of producing the desired pressure, which should be 100 lbs./sq. in. The pressure may be produced either by connecting the bomb to a tank of CO_2 (carbon dioxide), or to a tank of compressed air (if the air is dry), or by building up pressure with a hand pump attached directly to the bomb. A testing bomb of the hand pump type is shown in Fig.V. The hand pump plunger is labelled a, the pressure gage is at b, and a shielded spark plug is shown at c. The current for the spark may be produced from a booster magneto or a regular magneto run by a small electric motor. If, with the proper pressure in the bomb, a bright, steady spark across the points may be seen through the glass window, the plug may be considered satisfactory for use. If no spark occurs, or if there

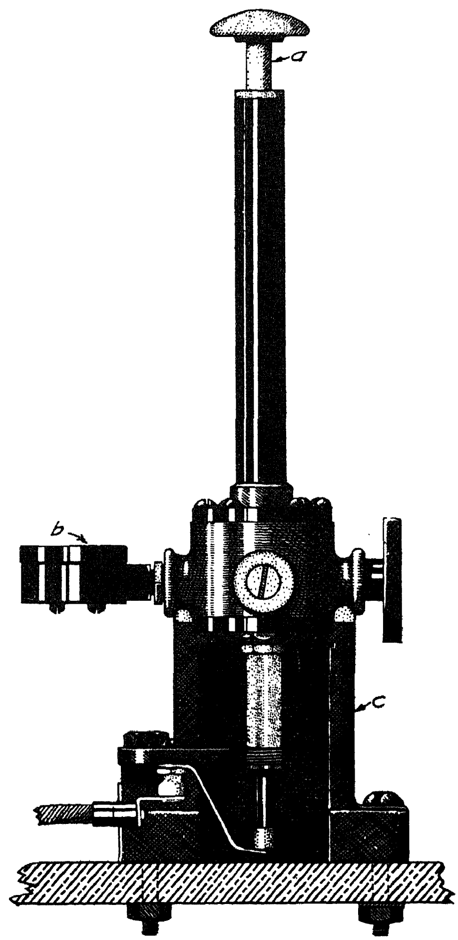


FIG. V

is an irregular spark, the plug is defective and if the short cannot be located and remedied, the plug must be scrapped. After the plugs have been tested and found satisfactory, they should be placed in a rack of some sort to prevent damage. If they are to be stored for any length of time, they should be coated with a light film of oil and preferably kept in a dry place such as a storage case or cabinet heated by one or more electric light bulbs.

Installation of Plugs - The following instructions are quoted from the B. G. Service Manual:

"When installing plugs in engines, do not use wrenches with handles more than 10" long. It is possible, if too much force is used in pulling down the plugs in the engine cylinders, to distort the plug shells and cause the cores to loosen in the shells. If solid copper gaskets are used, be careful not to pull the plugs down so tightly that the bronze cylinder bushing will be loosened in trying to take the plugs out later. Be particularly careful of this in putting plugs in an engine while it is still hot.

"Cylinder gaskets less than 1/16" in thickness should never be used.

"If using copper asbestos cylinder gaskets, there is more danger of the plugs becoming loose in the cylinders, so they can be pulled down tighter without danger of injuring the bronze cylinder bushing when the plugs are taken out. If it good practice to retighten the plugs after the first few hours of engine running when copper asbestos cylinder gaskets are used.

"The copper and asbestos type gaskets aid in maintaining maximum resistance to fouling in the cooled running engines. They allow the plug to run slightly hotter. Solid copper gaskets aid in reducing plug temperatures in the high compression or hot running engines.

"In installing radio shielded plugs, there is much more danger or pulling the plugs down so tightly as to distort the shells and cause the cores to loosen, as the harness and plug elbow may exert a loosening force on the cores. Do not pull the elbow connection nut down so tightly that the plug core will be loosened in the shell when the connection nut is backed off.

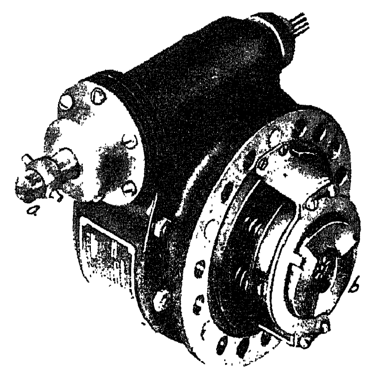
"In tightening the elbow connection nut on the shielded type plug, hold the ignition cable or harness so that any strain of the cable or harness will tend to tighten the plug in the shell rather than loosen it."

CHAPTER 11
STARTERS AND GENERATORS

The overhaul and repair of starters and generators is the work of a specialist and should not be undertaken except by an adequately equipped and authorized service station. This chapter is devoted to a discussion of the various types of starters and generators, an explanation of the principles of their operation, and instructions for the installation of the more common types. However, the information in the following pages should under no circumstances be understood to supplant the manufacturers' instruction manuals, which should be consulted before the mechanic attempts to do any work in connection with the units in question.

NON-ELECTRIC STARTERS

Hand-Turning Gears - Perhaps the simplest form of starter is the Eclipse hand-turning gear, illustrated in Fig. I. This type of starter is used on engines of low h.p., when no battery is carried in the airplane. It is operated by means of a handle which fits over the shaft, a, and engages the two pins indicated. The slot which fits the pins is in the form of a ratchet to eliminate any possibility of reversal of the movement of the handle in case the engine back-fires and the safety clutch in the starter fails to function. The installation of the handle is in general similar to that used on inertia starters and illustrated in Fig. VI. This starter is fastened to the starter flange on the engine, the attaching studs passing through the holes in the flange of the starter. A large number of holes are provided so that the starter may be set at almost any angle desired. Engagement to the crankshaft is by means of the ratchet clutch, b.



Courtesy Eclipse Aviation Corp.

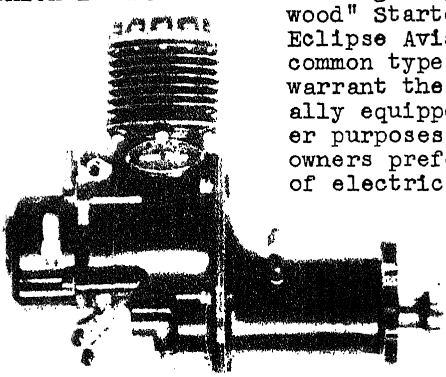
Fig. I

The general design of the starter includes a series of reduction gears operating an automatic engaging and disengaging mechanism through an adjustable torque overload release. This release automatically disconnects the starter drive if the engine fires backward. Starters of this type are often provided with a built-in booster magneto geared to the shaft which is turned by the handle, so that operating the crank not only turns the engine over but produces a hot spark from the booster.

The operation of the starter is simplicity itself, consisting merely of turning the crank until the engine starts, then removing the crank handle (if the handle is not permanently attached). If a booster is installed, the turning of the crank should be continued until it is evident that the engine will keep on running without

need of the booster.

The Air Injection Starter - This starter, the compressor for which is illustrated in Fig. II, was originally known as the "Heywood" Starter, but is now manufactured by the Eclipse Aviation Corporation. It is no longer a common type, since aircraft expensive enough to warrant the installation of a starter are usually equipped with a battery for radio and other purposes. When the ship is so equipped, most owners prefer to use one of the several types of electric starters.



Courtesy Eclipse Aviation Corp

FIG. II

The air injection starter consists of an engine-driven air compressor, a rotating distributor valve which is integral with the compressor, an air storage tank, an automatic pressure regulating valve, a starting valve operated by a handle on the instrument board or elsewhere in the cockpit, a pressure gage visible to the pilot, and a primer, which is also mounted within easy reach and is similar to the conventional primer pump.

From the distributor valve an air line of copper tubing leads to a ball check valve mounted on the cylinder head and opening into the combustion chamber. Another air line leads from the distributor valve to the air storage tank. The distributor valve is connected through gears to the pump drive shaft which is in turn geared to the engine crankshaft. By means of this valve, the compressed air may be led to each cylinder just after the piston passes top center on the firing stroke. As the air passes through the distributor valve on its way from the tank to the cylinder, a portion of it forces liquid fuel from a priming cup in the starter into the cylinder, thus giving a rich charge for starting.

The air is released from the tank by means of the starting valve which is operated by a handle in the cockpit. The use of this handle has already been described in the section devoted to starting and warming up in the chapter on "Operating the Engine."

The air which is used from the tank in starting the engine is replaced by the pump after the engine is running. When the pressure of 450 lbs./sq. in. is reached, the pressure regulating valve, which is an integral part of the storage tank automatically stops further charging of the tank. The compressor is then relieved from charging the tank and rotates freely under no load until air is used again for starting or for some other purpose. (This other purpose may be the operation of the landing gear or wing flaps, a few ships having been built with such an arrangement.)

The advantage of the air injection starter is its relatively low weight and the fact that it turns the engine at fairly high speed (about 650 r.p.m.), thus causing the magnetos to produce a

much better spark then is likely with other types of starters which turn the engine at a considerably lower speed.

The Combustion Starter - There are two makes of combustion starters in common use, the Coffman Starter, manufactured by the Breeze Corporation, and the Eclipse, manufactured by the Eclipse Aviation Corporation. The general principles are the same in both.

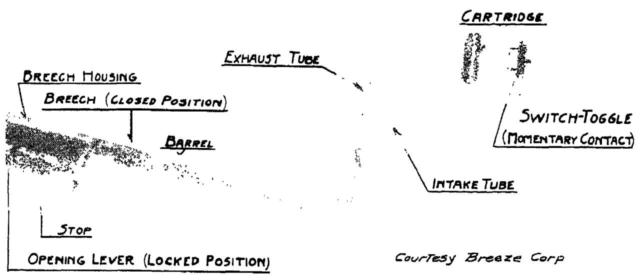


FIG. III

An illustration of the complete assembly of the Coffman Starter is shown in Fig. III. The Eclipse Cartridge Breech is illustrated in

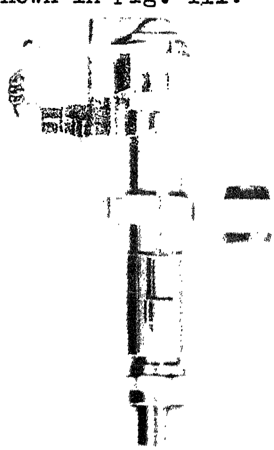


FIG. IV-A

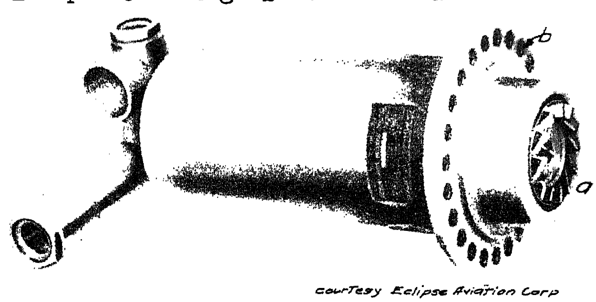


FIG. IV-B

Fig. IV-A, and the starter proper in IV-B. The principle of operation of these starters is as follows: A cartridge, which closely resembles an ordinary shot-gun shell, except for the size, is placed in the breech. (The cartridge is a little over 1" in diameter, and from 1-1/2" to 4" long, depending on the type of engine to be started.) The cartridge is inserted in the Coffman Starter by moving the breech-opener lever 90° upward and revolving the breech housing about its axis which opens the end of the breech barrel. When the cartridge has been placed in the breech barrel, the breech housing should be revolved to the

closed position and the opening lever moved downward against the stop.

After the breech has been closed, the engine is primed in the usual manner, the engine ignition switch turned on, and the starter switch operated. When the starter switch is closed, a circuit through the aircraft battery is completed and the cartridge is set off by an electrical spark. The charge of powder begins to expand in the breech, forcing the unburned portion of the charge through the intake tube and into the combustion chamber of the starter where the combustion is completed.

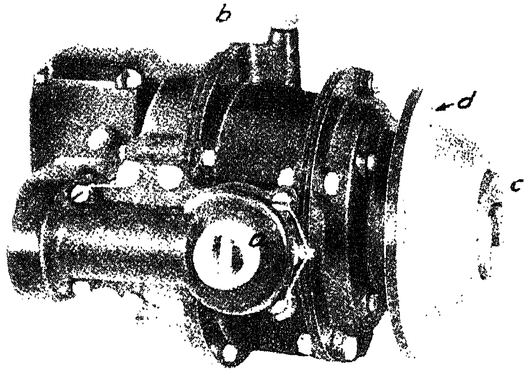
The burning of the powder produces a gas which expands with the heat of combustion. The action is identical with that which takes place in a shotgun when the trigger is pulled. The pressure caused by this expansion in the combustion chamber acts on the head of a piston in the starter, pushing it down. As the piston moves down, it causes the clutch jaw, a, Fig. IV-B, of the starter to engage with the engine clutch jaw. After engagement, the piston is caused to rotate by helical splines or threads with a very high lead. This rotation of the piston causes the engine crankshaft to rotate at a speed adequate for starting.

After the piston has completed its stroke and turned the crankshaft, the exhaust valve in the combustion chamber of the starter opens and the burned gas passes out through the exhaust tube. At the same time, the clutch jaw of the starter is automatically disengaged from the engine and the piston is returned to its original position by a coil spring. As the piston moves back, the exhaust valve closes. In case the engine is damaged so that it will not turn, if there is unburned carbon in the combustion chamber when the new cartridge is discharged, or if for any other reason the pressure inside the combustion chamber exceeds that which has been established as safe, a safety disc in the combustion chamber is ruptured and the pressure allowed to escape. When this occurs, a new safety disc must be installed before the starter can be used again.

Combustion starters are lighter than any other type which can be used on large engines. They are also quite efficient, producing energy enough to spin a cold engine of the most powerful type. They are not particularly common on commercial aircraft, possibly because of the expense of operation. (Each cartridge costs about thirty cents.) However, they are widely used on Army and Navy ships, due to the fact that the weight saved when they are substituted for the heavier electric types may be used for ammunition or other military load. These starters are mounted on the standard starter flange of the engine just as any of the hand or electric types. The holes for the mounting studs may be seen at b, in Fig. IV-B.

Hand Inertia Starters - Before going into a discussion of the principles of the Inertia starter, it is perhaps advisable to define the word "inertia" which is frequently thought of as the tendency of an object to remain stationary. However, the true definition is "the tendency of a body to continue in its state of rest or motion until acted upon by some outside force."

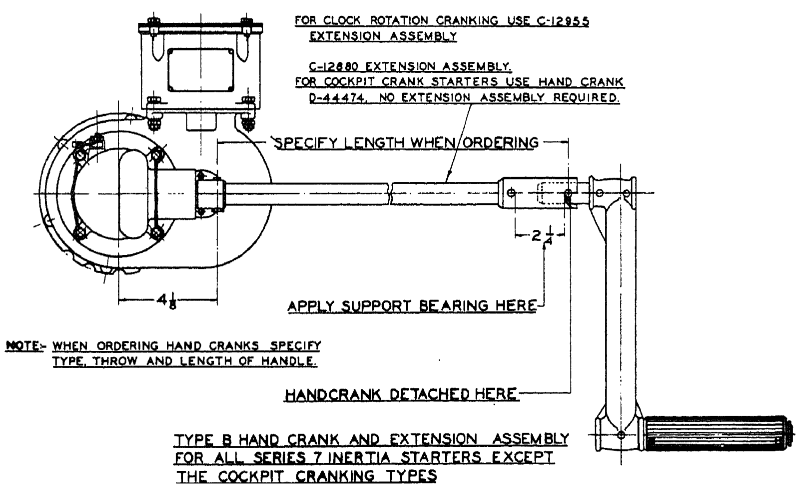
The basic design of the inertia starter involves the storage of energy in a small, heavy flywheel by accelerating it to a high rotational speed, then engaging it, by means of a clutch and gears, to the engine crankshaft. The momentum, or inertia, of the spinning flywheel is thus transferred to the crankshaft and turns the engine over rapidly through several revolutions. The flywheel may be brought up to the proper speed either manually or electrically. If the latter, the device is referred to as an electric inertia starter, which is discussed in the next section. Fig. V shows an Eclipse Series 6 Hand Inertia Starter with built-in booster magneto. The connection for the hand crank is shown at a, and the arm or bell-crank to which the clutch engaging control is connected, at b. From this arm a cable or rod is led either to the pilot's cockpit or to a point near the crank handle.



Courtesy Eclipse Aviation Corp.

FIG. V

In Fig. VI is shown a hand crank assembly for the Eclipse Series 7 Inertia Starter. It will be noted that the crank proper is connected by means of a ratchet to a shaft which is attached to the starter. The reason for the ratchet feature is that when the flywheel is brought to the proper speed by turning the handcrank, the

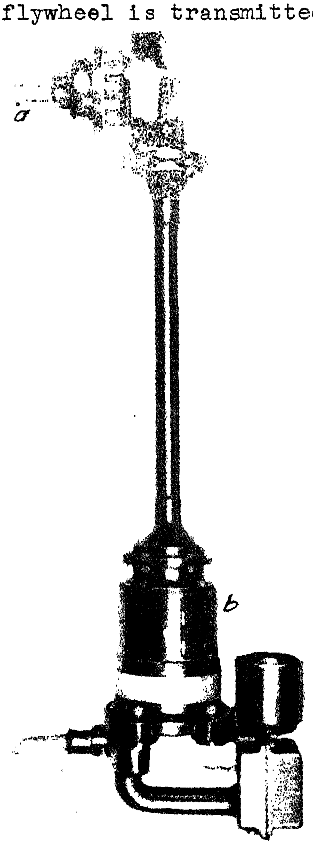


Courtesy Eclipse Aviation Corp.

shaft will continue to rotate as long as the flywheel is spinning. Hence, if the engine should start as soon as the clutch were engaged and before the energy in the flywheel were entirely absorbed, the crank would continue to turn until the flywheel came to a stop. The crank is made removable, of course, since it would offer considerable resistance to the air if left attached.

The actual cranking of the engine by the starter does not occur until the flywheel has been brought to the proper speed. Hence, the effort required to accelerate the flywheel is entirely independent of the size or stiffness of the engine, the temperature, or any other factor. This means, in the case of the electrically operated type that there is no greater drain on the battery to start a stiff engine than to spin one which turns easily.

The starter is attached to the crankcase by means of studs which pass through the holes at d. There are a large number of these holes though only six studs are provided, as a rule. In this way the starter can be set at almost any desired angle. The energy of the flywheel is transmitted through a ratchet clutch which is shown at c, in Fig. V. Since this clutch is of the ratchet type, it is automatically released as soon as the engine speed becomes greater than the speed of the starter. Furthermore, when the engaging mechanism (which is connected at b in Fig. V) is released, the entire ratchet is withdrawn entirely clear of the mating part on the crankshaft.



Courtesy Eclipse Aviation Corp.
FIG. VII

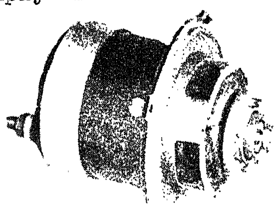
Some inertia starters, such as the one illustrated, are equipped with an integral booster magneto which is geared to the shaft of the flywheel. This functions as any other booster and serves to supply a hot spark even though the engine is turning at a relatively low speed.

The Eclipse External Energizer - On large airports or at the important bases of airlines, hand inertia starters are often actuated by an external energizer such as that illustrated in Fig. VII. The shaft and pin at a fit into the cylindrical end of the starter drive shaft in place of the crank handle. The shaft, a, is driven through bevel gears by means of an electric motor, b, which in turn is operated by current from a storage battery carried in a truck and not a part of the equipment of the airplane. This external energizer relieves the mechanic of the labor of "winding up" the starter, and obviously makes it unnecessary to carry a starting motor, a battery, and a generator in the airplane, resulting in an appreciable saving in weight.

The energizer is equipped with a torque overload release in the form of a multiple disc clutch which prevents over-taxing the motor and also lessens any torque reaction on the operator as the unit begins to turn the starter. The motor is reversible, so that it may be used on any starter regardless of its direction of rotation.

ELECTRIC STARTERS

Electric Inertia Starters - The electric inertia starter is simply the hand inertia type equipped with a motor to spin the flywheel. The basic type accelerating motor manufactured by the Eclipse Aviation Corporation is shown in Fig. I.



Courtesy Eclipse Aviation Corp.

FIG. I

In case the battery, which supplies the current for the starting motor, loses its charge for any reason, the electric inertia starter can always be manually operated, just as though no motor were provided. This is an extremely valuable feature, since in cold weather or under any conditions which are adverse to easy starting, it is entirely possible to run the battery down before the engine begins to run. This might be a serious situation if it were not possible to operate the starter manually. The fact that the starter can be cranked by hand is often utilized to save the battery from undue strain, or when it is feared that the battery charge is low. In such circumstances many mechanics have the pilot or the person in the cockpit use the electric motor while the starter is being cranked by hand. This combination of effort relieves the battery to a great extent and at the same time calls for much less energy on the part of the person turning the crank than would be the case if no motor were available.

In operating the electric inertia starter it is, of course, necessary to close the electrical circuit between the battery and the motor and, when the starter has been brought up to the proper speed, engage the clutch. These two operations are accomplished through a single push button switch, one type of which is shown in Fig. II. Although it is possible to use a switch heavy enough to handle the entire current running from the battery to the motor, this practice is not ordinarily followed. Instead, a solenoid starting relay, illustrated in Fig. III, is commonly used to close the circuit between the battery and the starter. When this device is installed, the heavy wires carrying the current from the battery to the starting motor are connected to the switch in the relay, which is actuated by the solenoid. The solenoid is energized by a small amount of current which passes through the push button switch, shown in Fig. II. This arrangement makes it possible for the wires carrying the heavy current to be comparatively short, with consequent saving in weight, and hence is almost universally employed.

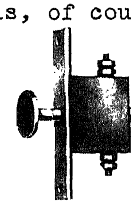


FIG. II

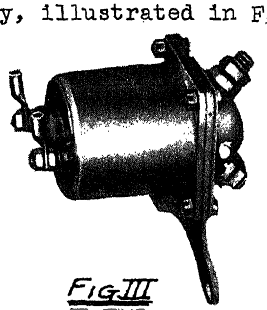
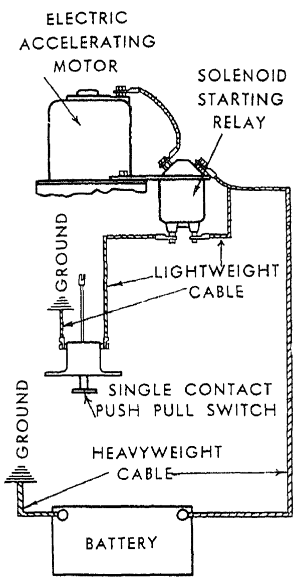


FIG III

The clutch may be engaged either manually, in which case the engaging cable is run from the arm on the starter, previously mentioned, to the shaft of the switch button. When so connected, the starter is operated by pushing the button until the flywheel has been brought up to speed, as indicated by the whine of the gears (usually requiring from five to ten seconds), after which the button



Courtesy Eclipse Aviation Corp.

FIG. IV

is pulled to engage the clutch. A wiring diagram showing the entire installation except for the connection between the clutch operating arm and the switch is shown in Fig. IV. The cable, or rod, from the clutch engaging arm is connected to the forked end of the switch shaft shown at f. It should be remembered that this is purely a diagram and that actually the lightweight cables are relatively long since they must extend from the cockpit to the engine, whereas the heavyweight cables are relatively short, since they must reach only from the battery to the engine, and the battery is commonly mounted in the engine compartment.

Instead of an integral booster magneto such as is common on hand inertia starters, electric inertia starters are often fitted with booster coil, by means of which the current from the battery is converted to high tension and passes through the distributor of the engine magneto, as previously discussed in the chapter devoted to Ignition. An Eclipse shielded battery booster coil is shown in Fig. V. A wiring diagram of a system which uses a booster coil and a manually operated clutch is shown in Fig. VI. This diagram, which was supplied

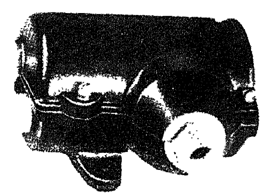


FIG. V

12 V. SYSTEM				24 V. SYSTEM			
TABLE BASED ON 2 V CABLE DROP AT 500 AMPS				TABLE BASED ON 4 V. CABLE DROP AT 300 AMPS.			
LET.	WIRE SIZE	CIR. MIL AREA	TOTAL CABLE LENGTH NOT TO EXCEED	LET.	WIRE SIZE	CIR. MIL AREA	TOTAL CABLE LENGTH NOT TO EXCEED
A	#0	105,500	40 FT	C	#6	26,250	33 FT.
B	#2	66,370	25 FT	D	#8	16,510	21 FT.

CAUTION

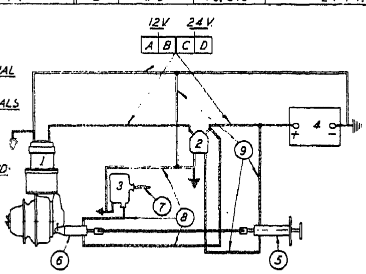
MOTORS FITTED WITH ONE TERMINAL POST ARE GROUNDED INTERNALLY.

MOTORS FITTED WITH TWO TERMINALS MAY BE CONVERTED TO ONE WIRE GROUNDED SYSTEMS BY REPLACING THE INSULATING WASHER ON EITHER TERMINAL POST WITH A STEEL GROUND·

TWO WIRE SOLENOID SWITCHES MAY BE CONVERTED TO ONE WIRE GROUNDED SYSTEMS BY REPLACING EITHER TERMINAL INSULATING BUSHING WITH A GROUNDING BUSHING.

MOUNT ALL BOOSTER COILS ON A GROUNDING BASE AS THE SECONDARY WINDING IS GROUNDED INTERNALLY FOR BOTH ONE AND TWO WIRE SYSTEMS.

TO CONVERT ONE WIRE GROUNDED BOOSTER COIL FOR TWO WIRE UNGROUNDED OPERATION REMOVE THE GROUNDING WASHERS AND INSULATE THE PRIMARY TERMINAL POST.

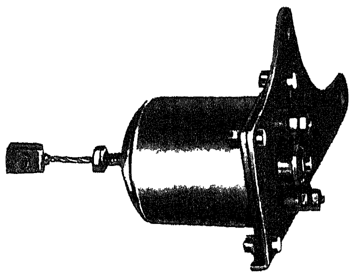


1 STARTER MOTOR
2 SOLENOID STARTING SWITCH
BOOSTER COIL
SINGLE CONTACT PUSH PULL SWITCH
BOOSTER COIL PULL SWITCH
TO DISTRIBUTOR
8 NO.16 CAMBRIC INSUL. CABLE
9 NO.14 CAMBRIC INSUL. CABLE

NOTE:- FOR ONE WIRE GROUNDED SYSTEMS USE SECTIONED LINES ONLY.
FOR TWO WIRE UNGROUNDED SYSTEMS DISCONNECT ALL GROUND WIRES AND USE FULL LINES IN ADDITION TO SECTIONED LINES.

WIRING DIAGRAM FOR ELECTRIC INERTIA STARTER COMPLETE WITH BOOSTER COIL SWITCH, BOOSTER COIL, SOLENOID STARTING SWITCH AND SINGLE CONTACT PUSH PULL SWITCH

Courtesy Eclipse Aviation Corp.



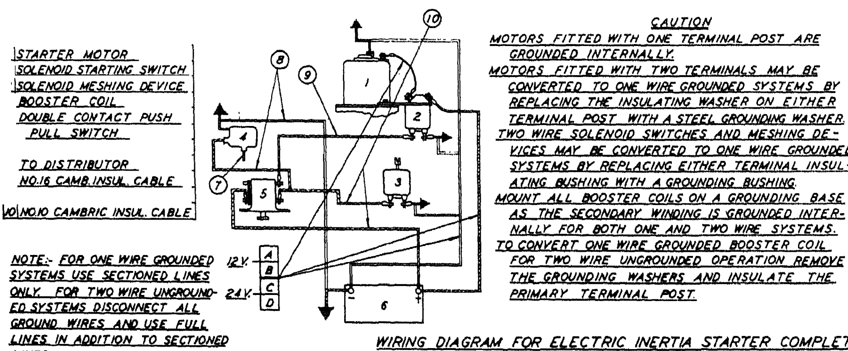
Courtesy Eclipse Aviation Corp.

FIG. VII

through the courtesy of the Eclipse Aviation Corporation also gives the sizes of all wires.

Where the engines are located at a relatively great distance from the cockpit, as in the case of twin or four-engined aircraft, it is frequently difficult to arrange for manual engagement of the clutch. In such cases, it is customary to use a solenoid engaging device, such as that illustrated in Fig. VII. This unit consists of a solenoid energized by the battery, and connected by means of a cable or rod to the clutch-engaging arm. The cockpit switch used in this case is of the double contact type. When the button or handle is pushed, the solenoid starting relay closes the circuit between the battery and the starting motor, which brings the starter up to the proper speed. The button is then pulled, which closes the circuit between the solenoid engaging device and the battery, thus engaging the clutch. A wiring diagram, showing this hook-up, is shown in Fig. VIII. The connection from the solenoid engaging unit, 3, to the

12 V. SYSTEM				24 V. SYSTEM			
TABLE BASED ON 2 V. CABLE DROP AT 500 AMPS.				TABLE BASED ON 4 V. CABLE DROP AT 300 AMPS.			
LET.	WIRE SIZE	CIR. MIL AREA	TOTAL CABLE LENGTH NOT TO EXCEED	LET.	WIRE SIZE	CIR. MIL AREA	TOTAL CABLE LENGTH NOT TO EXCEED
A	#0	105,500	40 FT.	C	#6	26,250	33 FT.
B	#2	66,370	25 FT.	D	#8	16,510	21 FT.



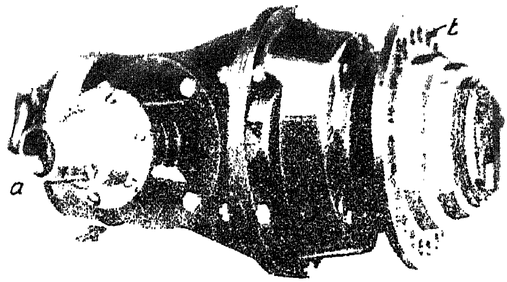
WIRING DIAGRAM FOR ELECTRIC INERTIA STARTER COMPLETE WITH BOOSTER COIL, SOLENOID STARTING SWITCH, SOLENOID MESHING DEVICE AND DOUBLE CONTACT PUSH PULL SWITCH

Courtesy Eclipse Aviation Corp.

clutch operating arm is not indicated in the diagram. This connection may be either aircraft control cable or a small steel rod. Whichever is used, some means of adjustment should be provided so that there is no slack in the mechanism. In the case of a cable, a turnbuckle makes a satisfactory adjustment. When a rod is used, the ends may be threaded and equipped with yokes or terminals screwed on the thread. These yokes must naturally be provided with a lock or jam nut to prevent accidental change of adjustment.

Direct Electric Starters - The direct electric starter consists of an electric motor, a gear reduction, and an automatic engaging

and disengaging mechanism which operates through a torque overload release. The Eclipse E-160 Direct Cranking Electric Starter is illustrated in Fig.IX. It will be noted that this starter is provided with a connection for a hand crank, shown at a, by means of which the engine can be turned, through the reduction gears, in case of battery failure. The starter is attached to the engine by means of the bolt holes at b, just as the other types previously discussed.



Courtesy Eclipse Aviation Corp.

FIG. IX

In starters of this type the engine is cranked directly by the starter without any preliminary storage of energy as in the case of the inertia type. Hence, if the engine is unduly stiff, the drain on the battery will be proportionately greater. On the other hand, there is no waiting to bring a flywheel up to a satisfactory speed. This feature is particularly valuable in seaplanes, where instantaneous starting is highly desirable, and often is a means of avoiding damage to the ship caused by its drifting into obstructions while the pilot is waiting for the engine to start.

Not all of the direct electric starters are provided with a hand crank. On the models used with the smaller engines this feature is customarily omitted since such engines can usually be started by pulling the propeller.

The current from the battery to the starter may be carried through the cockpit starter switch, but unless the engine is close to the cockpit, it is better to use a solenoid starting relay similar to that illustrated in Fig. III. The circuit, in this case,is practically identical with that illustrated in Fig. IV.

The operation of the starter is extremely simple, consisting of merely pushing a button, which may be mounted accessible to the feet or the hand, depending upon which is the more convenient. In other words, this starter is handled exactly as those commonly used in automobiles. However, if the engine does not start after a few revolutions, the push button should be released for a few seconds, after which another effort to start may be made. If, after several attempts, the engine still refuses to start, an investigation of possible trouble should be made, as outlined in the chapter on "Trouble Shooting."

GENERATORS

Since the installation of electrical accessories, such as starters, landing lights, retractable landing gear units, radio and the like, has become increasingly common, even the smaller types of airplanes are usually equipped with storage batteries. These batteries will become exhausted very rapidly unless kept charged while in flight. This requires that a generator be mounted on the engine.

Practically all of the aircraft generators are manufactured by the Eclipse Aviation Corporation, through whose courtesy the illustrations and descriptive matter in this section are supplied.

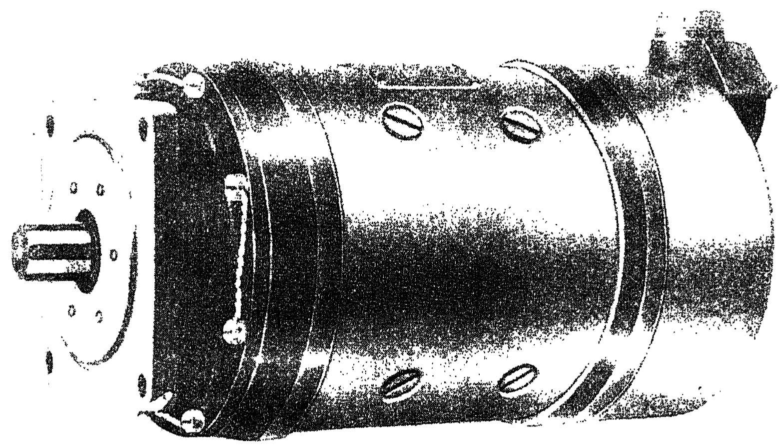
The electrical system of an airplane presents problems different from those encountered in the automobile, although the basic principle is the same. In the airplane, the engine is running continuously at an r.p.m. which is near its maximum, so that there is a tendency for the generator to maintain an extremely high output. If the operation is during daylight, there is practically no current being drawn from the battery, and even at night the consumption is small except when the landing lights are being used. On the other hand, a large amount of current is needed for starting and for the operation of various electrical devices (landing gears, flaps, etc.) through short periods of time, so that the generator must be capable of recharging a practically exhausted battery very quickly. This combination of circumstances has required that a special type of system be worked out for aircraft.

The Eclipse Company has developed a means of regulating the voltage, put into the battery by the generator, which takes care of the intermittent load requirements while at the same time preventing overcharge of the battery. The following description is quoted from the literature of the manufacturers:

> "The Eclipse regulating mechanism is contained in a separate cushion-mounted control box. Its operation is automatic and the output of the generator unit is held at a pre-determined constant voltage. The voltage regulating unit within the control box is normally adjusted for a constant voltage of either 14.2 or 28.4 volts, which values are most suitable for use with 12 or 24 volt battery systems. The current output of the generator is automatically varied in accordance with the state of charge of the battery and in addition, the amount of current which is being drawn from the battery and generator at that time. The combination of these conditions is the basis upon which the generator charging rate is automatically varied by the control box. Thus the proper charge is delivered to the battery at all times without danger of over-charging. A discharged battery will receive the maximum charging rate and as the charging proceeds (providing external load requirements do not equal or exceed the generator capacity), the charging rate is reduced proportionately, tapering off to a trickle charge when the battery has become fully replenished.
>
> "To preclude the possibility of the generator's becoming overloaded, with resultant overheating due to abnormal or excessive load requirements, a current limitator unit is provided within the control box; its function being to limit the maximum current output to a value slightly in excess of the rated capacity of the generator.

"In addition to the other features of regulation and control performed by the control box, there is included a unit termed a reverse current cut-out. This device prevents the battery from discharging through the generator when the generator is at rest or operating at a driven speed at which it is not developing its normal voltage. The cut-out automatically connects and disconnects the generator to and from the battery at the proper time."

Installation - Fig. I shows a Type E Single Voltage Eclipse Generator. This generator mounts on the standard 5" SAE Generator

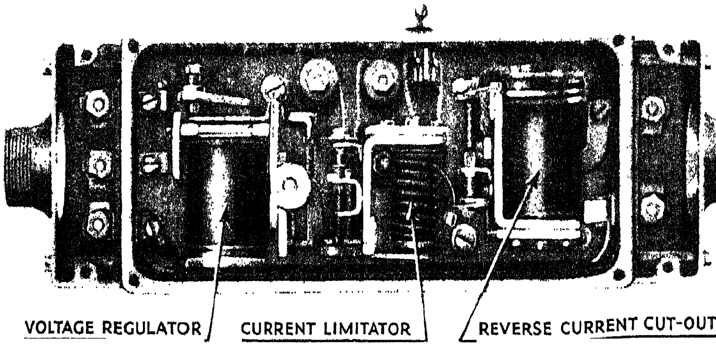


Courtesy Eclipse Aviation Corp.

FIG. I

Mounting Flange with which all of the larger engines are provided. To install the generator, the plate and gasket covering the generator drive and mounting flange on the engine crankcase should be removed. The mounting flange should be wiped clean and the gasket replaced. The rotation of the engine drive shaft should be checked to see that it is correct for the generator being used. The rotation of the generator is specified facing its drive end. It may be reversed, but it is recommended that work of this nature be done by an authorized service station. After the direction of rotation has been checked, the generator may be mounted on the studs provided on the engine and the nuts tightened down.

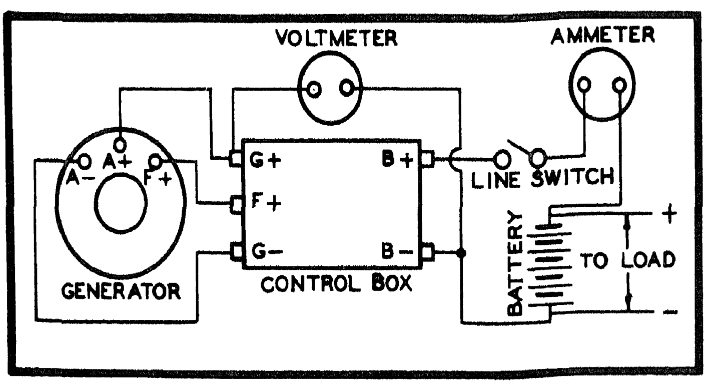
The control box may be located at any convenient place where it is accessible for inspection. Care should be taken to have the vibration reduced to a minimum. After it has been mounted, the wiring should be installed. A view of the Eclipse three-unit standard control box, with the cover removed, is shown in Fig. II, and an external wiring diagram for the system in Fig. III. Good quality flexible insulated cable of the proper size should be used. The cable from F+ on the generator to F+ on the control box should be not less than No. 18 B&S. The other wires, if the generator is less than twenty feet from the control box, should be No. 14 B&S for a 15 amp.



Courtesy Eclipse Aviation Corp

FIG. II

generator, No. 10 B&S for a 20 or 25 amp. generator, No. 8 B&S for a 50 amp. generator. If the generator is more than twenty feet from the control box these wires should be No. 12 B&S for the 15 amp. generator, No. 8 B&S for the 20 and 25 amp., and No. 6 B&S for the 50 amp. The ends of all cables should be fitted with terminals, as previously described. Care should be taken that the voltmeter and ammeter are of sufficient capacity.



Courtesy Eclipse Aviation Corp.

FIG. III

The operation of the generator and control box is entirely automatic when the engine is started with the line switch in the closed position. The operation of the generator should be checked before each flight by opening the engine up to approximately 1600 r.p.m. If the ammeter shows no charge at this speed, the operation of the system should be checked by qualified service mechanics.

CHAPTER 12
INSTRUMENTS

This chapter is devoted to a discussion of the various instruments required for satisfactory indication of the functioning of the engine and its accessories. The general principles of these instruments are explained and instructions for their installation are given. The overhaul and calibration of instruments does not fall within the scope of the mechanic's duties and should be taken care of by the manufacturer or an authorized representative. Furthermore, since this volume concerns itself particularly with engines, flight instruments and any others which do not pertain directly to the power plant are omitted.

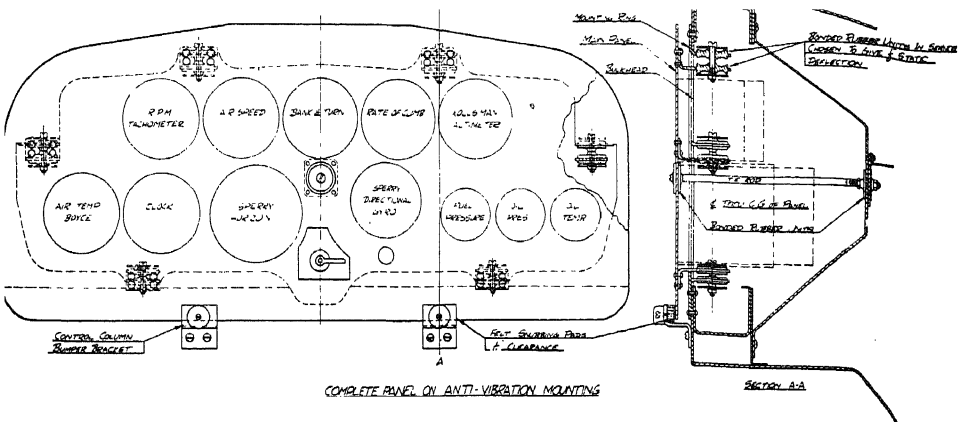


Fig. I

Practically all instruments are designed for mounting on an instrument panel or board. This board is frequently supported on rubber to eliminate undue vibration. A typical anti-vibration mounting, made with Lord vibration absorbers, is shown in Fig. I. A cross-section of one of the vibration-absorbing units is shown in Fig. II-A, and a photograph of a single unit in Fig. II-B.

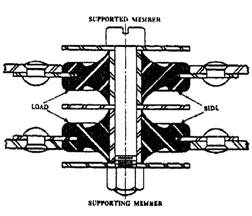


Fig. II-A

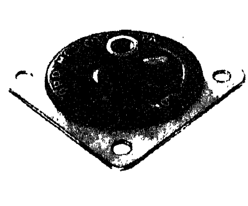
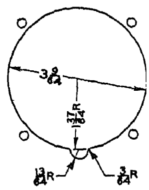


Fig. II-B

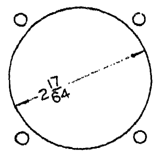
The attachment of the instruments to the panel itself, which is usually of sheet duralumin, is very simple. A hole of the proper size is cut in the panel and small holes for four mounting screws are drilled. The face of the instrument is pushed through from the back of the panel, so that the mounting flange is not visible from the front, and the instrument bolted in

place. Standard instruments are almost invariably one or the other of two sizes. The larger size requires a hole 3-9/64" in diameter, while the hole for the smaller must be 2-17/64". In addition, on certain instruments which are provided with a knob for setting, it may be necessary to cut a small amount of material from the rim of



DRILL FOUR HOLES NO. 18 (.169)
EQUALLY SPACED ON 3 1/2 DIAMETER

Fig. III



DRILL NO. 18 (.1695) 4-HOLES
EQUALLY SPACED ON 2 5/8 DIAMETER

Fig. IV

the large hole, as indicated in Fig. III, which gives the mounting dimensions for a Kollsman Manifold pressure Gage. These dimensions are standard for all the large type Pioneer and Kollsman instruments. The Pioneer instruments are usually attached with No. 8 machine screws, and the Kollsman with No. 6.

Fig. IV gives the mounting dimensions for the smaller type of instruments. Temperature and pressure gages are usually made in this size. Since practically all of the instruments will fit one or the other of the cut-outs shown, no further instructions for instrument board installation will be given, except where the procedure varies from that discussed above.

TACHOMETERS

The tachometer indicates the r.p.m. of the engine, and hence is one of the most important instruments. There are three types of tachometers in general use: the centrifugal, the magnetic, and the electric. Another type, once widely used but seldom found today, is the chronometric.

The Centrifugal Tachometer - The centrifugal tachometer is probably the most common of the three types. Fig. I shows a Pioneer centrifugal tachometer arranged to show r.p.m. up to 3,500, the inside arc carrying the figures for readings above 2,500.

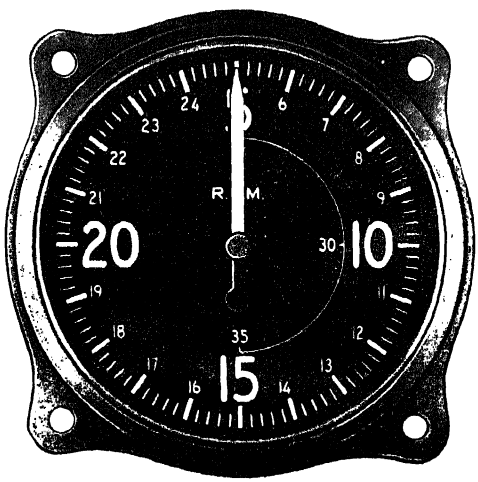


Fig. I

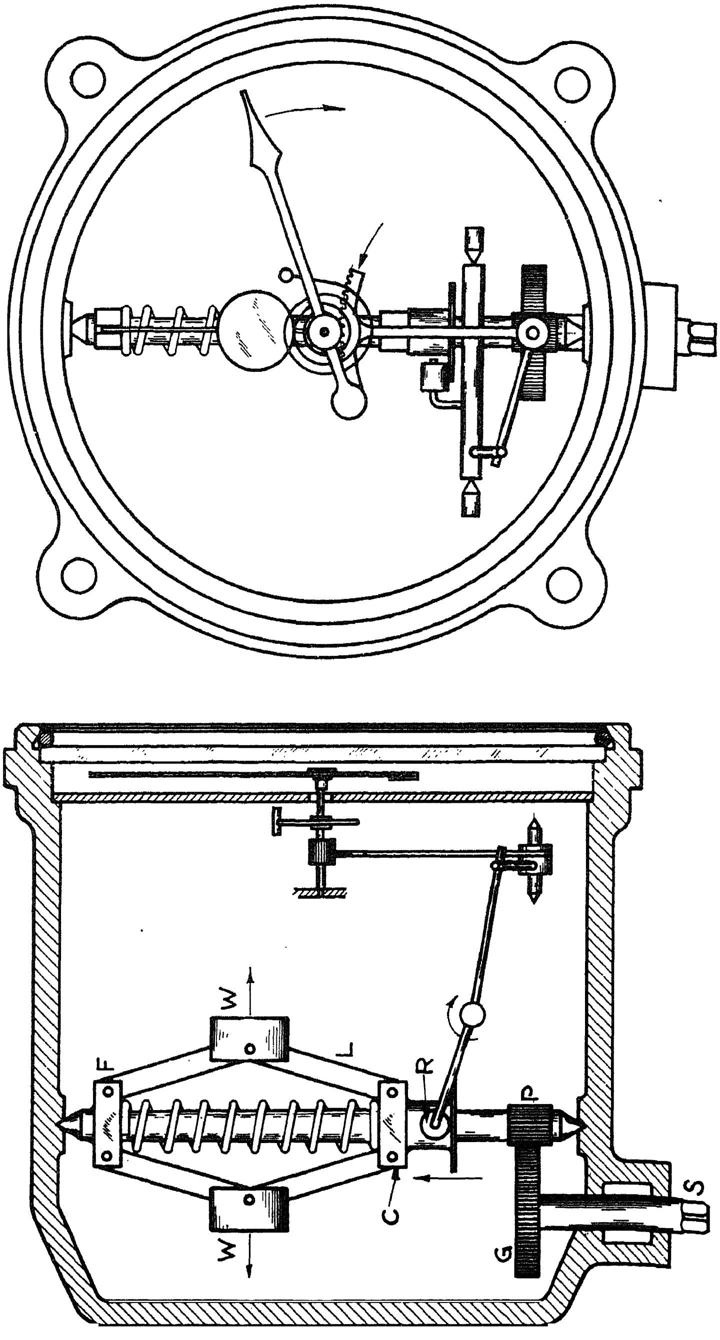


FIG. II

Fig. II is a schematic drawing of the inside of the instrument and illustrates the principles involved. The operation of this instrument depends upon centrifugal force, the intensity of which is determined by the speed of the rotating object. The mechanism is actuated by a flexible drive shaft, connected at one end to the engine and at the other to the shaft, S. The flexible shaft usually consists of a core of spring steel wire, surrounded by a coil of smaller wire, its appearance being that of a long, helical spring. Enclosing this shaft is a housing of flexible tubing, provided with fittings at each end. These fittings screw on the tachometer connection of the engine, and, at the other end to the boss, B, of the tachometer head. This boss is provided with external threads not shown in the drawing.

The gear, G, attached to the shaft, S, drives the pinion, P, at a high rate of speed. The flyweights, W, are mounted on the ends of links, L, which are connected to the collars, F, and C. The collar, F, is fixed to the pinion shaft, but the collar, C, is free to slide up and down the shaft. This lower collar is provided with a flange, on which the roller, R, rides. The helical spring, wrapped around the pinion shaft between the collars F and C, tends to hold them apart and keep the weights, W, close to the shaft. When the shaft rotates, the weights must rotate with it, and through centrifugal force tend to move away from the shaft in the direction indicated by the arrows at W. As these weights move out they pull the collar, C, up the shaft towards the collar, F. The roller, R, is necessarily carried up with the collar, C. This movement actuates the remainder of the mechanism, the various parts of which move in the direction indicated by the arrows shown in the front view (on the upper part of the illustration). Since the centrifugal force is proportional to the speed of rotation, the dial may be graduated so that the hand indicates the r.p.m. of the engine. The coil spring shown around the center of the shaft which carries the indicator hand is used simply to maintain a slight tension and prevent fluctuation of the hand.

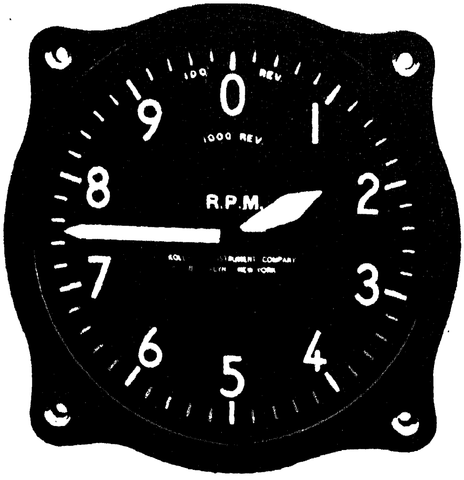


Fig. III

<u>The Kollsman Magnetic Tachometer</u> - The face of this instrument, one model of which is illustrated in Fig. III, is the same in general appearance as all other tachometers. It may be obtained with two hands, or pointers, the longer of which makes an entire revolution of the dial for each hundred r.p.m. Since these divisions are subdivided into five parts, variations of twenty r.p.m. are accurately indicated. The shorter hand moves through one numbered division for each thousand r.p.m. Thus, the reading on the instrument shown in Fig. III indicates 1,750 r.p.m.

The following description is quoted from the manufacturer's manual: "The tachometer consists essentially of a powerful magnetic rotor, driven by a flexible shaft through a gear transmission, an inductor drum mounted for rotation around the rotor, and a calibrating spring for the inductor.

"The rotating magnetic field of the rotor generates an electric current in the inductor, which, in turn, causes a torque of the inductor against the calibrating spring. As a result, the inductor is rotated to that position where its torque is balanced against the calibrating spring. This rotation is proportional to the speed of the rotor, and therefore to the speed of the engine.

"The pointers, connected to the inductor shaft, indicate, in terms of r.p.m., on an evenly spaced scale, accurately, steadily, without oscillation or jumpiness."

<u>The Electric Tachometer</u> - Several companies manufacture electric tachometers. The great advantage of this type lies in the fact that the accuracy of the reading is not affected by the distance between the instrument and the engine. When a mechanical tachometer is installed at some distance from the engine, as in the case of large, multi-engine airplanes, the length of the flexible drive shaft is likely to affect the accuracy of the reading, due to the springiness and whip of the shaft. This is a serious objection, especially where it is necessary to synchronize several engines. The electric tachometer eliminates this difficulty, since there are no moving parts between the engine and the instrument.

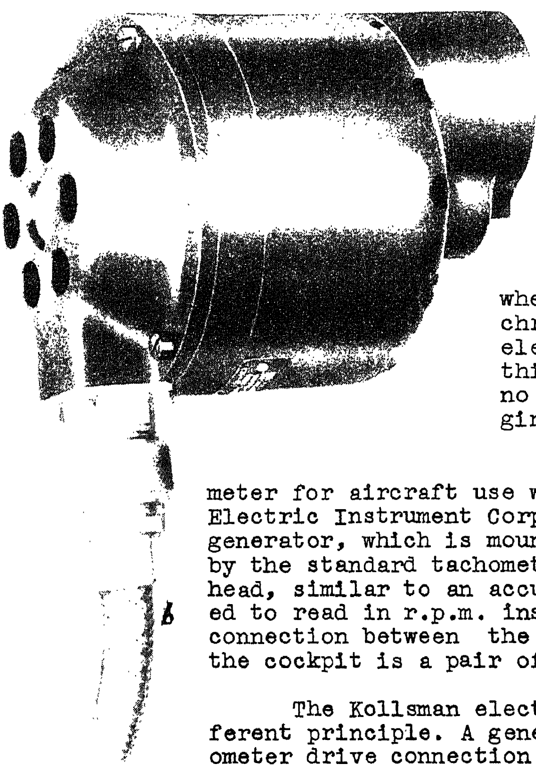


Fig. IV

The first electric tachometer for aircraft use was brought out by the Weston Electric Instrument Corporation. It consists of a generator, which is mounted on the engine and driven by the standard tachometer drive, and an indicating head, similar to an accurate voltmeter, but calibrated to read in r.p.m. instead of volts. Thus, the only connection between the engine and the instrument in the cockpit is a pair of electrical cables.

The Kollsman electric tachometer employs a different principle. A generator is mounted on the tachometer drive connection on the engine and an indicator on the instrument board just as in the case of the Weston tachometer; however, the indicator contains, instead of a voltmeter, a small motor which

runs in synchronism with the generator. The indicator hand is moved by means of a small magnetic drag tachometer which accurately shows the r.p.m. The face of this instrument is the same in general appearance as that of the conventional type. The generator for the Kollsman electric tachometer is shown in Fig. IV. This is connected to the tachometer drive on the engine by the nut, a. The shielding for the cables running to the instrument is shown at b.

Tachometer Installation - The instrument, or indicating head, is fastened to the instrument panel by the method previously described. In the case of the centrifugal and magnetic types, the shaft installation is an important consideration. The connection of the two ends of the drive shaft is extremely simple, consisting merely of fitting the ends of the shaft to the instrument and engine, respectively, and tightening the retaining nut. However, sharp bends in the drive shaft are extremely undesirable, since the shaft itself rubs against the housing, causing undue wear as well as inaccurate readings. Accordingly, the lead from the instrument to the engine must be as straight and direct as possible. The housing should be protected against chafing wherever it passes a structural member and furthermore must be supported wherever possible by small metal clamps, safety wire, or friction tape, properly shellacked.

In the case of electric tachometers, the cables from the generator to the instrument must also be properly supported, but sharp bends are of no importance, provided the cable is not kinked. It is desirable to consult the instruction manual of the manufacturer before installing electric tachometers in order to avoid any possibility of making an incorrect electrical hook-up.

PRESSURE GAGES

The pressure gages referred to under this heading are those used chiefly for indicating the pressure in lbs./sq.in. at which the lubricating oil is being pumped through the engine; or the pressure at which the fuel is being delivered to the carburetor. Pressure gages are also used to indicate the pressure in hydraulic mechanisms, such as landing gear hoists, flap controls, etc., and for showing the pressure in storage tanks, such as those used for injection starters and for pressure fire extinguishers. The principle employed in all of these is the same, but the capacity varies. For example, a pressure gage for an injection starter will indicate pressures up to 600 lbs./sq.in; oil pressure gages usually read from 0 to 120 or 200 lbs./sq. in. Manifold pressure gages are not included in this group, since the principle of their operation is usually different. A Kollsman oil pressure gage is illustrated in Fig. I. This gage indicates oil pressures up to 120 lbs./sq. in.

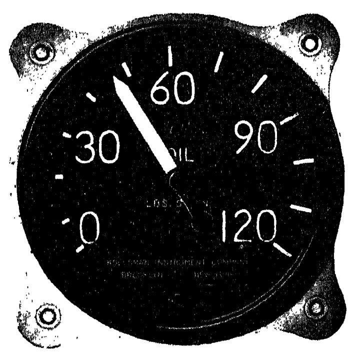


Fig. I

A diagram of the Pioneer pressure gage is shown in Fig. II. The principle employed in this gage is that usually found in such

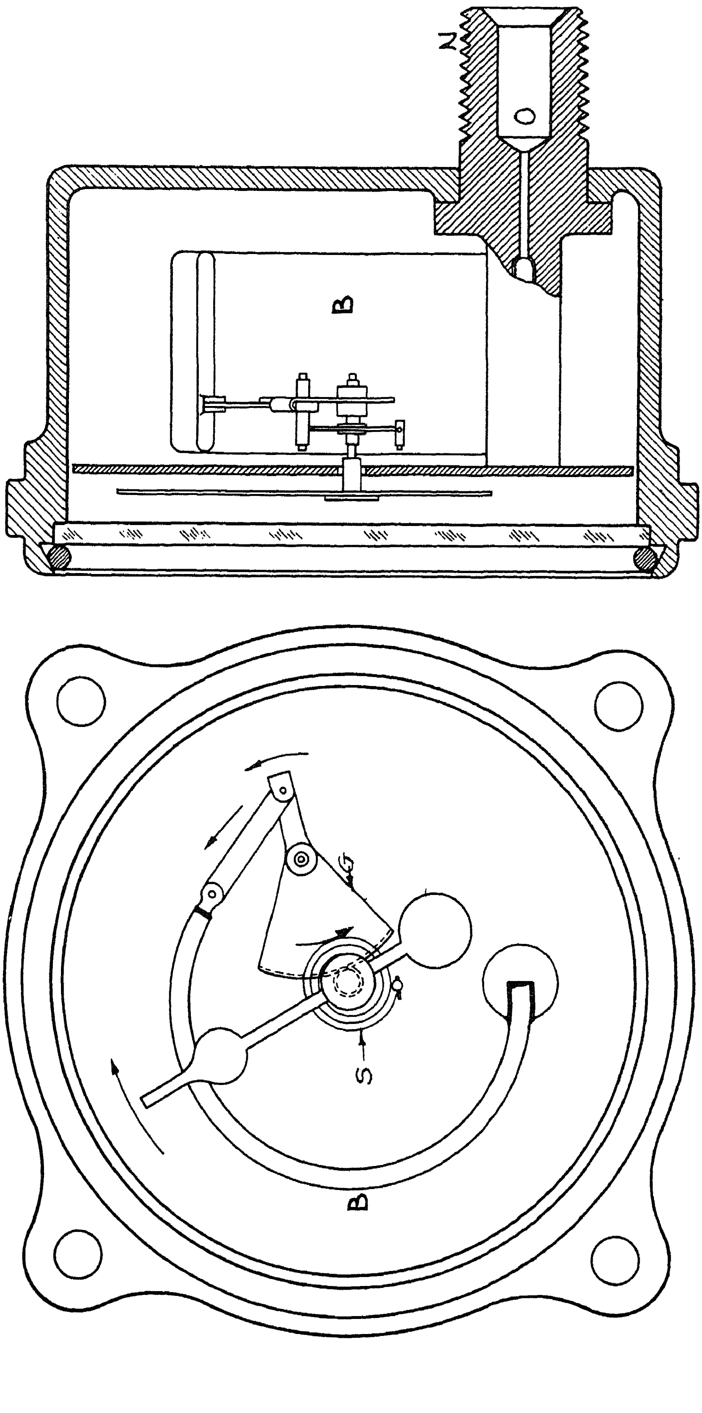


FIG. II

such instruments. The gage is actuated by means of a Bourdon tube, shown at B, in Fig. II. This tube is made of spring-tempered brass or bronze tubing of elliptical cross-section. It is sealed at one end and connected at the other to the feed line, N. The liquid passes through the opening, O, and into the Bourdon tube. If pressure is applied to the liquid, the Bourdon tube tends to straighten out. As it straightens, it operates, through suitable linkage, the geared sector, G. This sector meshes with a gear on the shaft which carries the indicator hand or pointer. The shaft is stabilized and kept from vibrating by the coil spring, S. The linkage is so arranged that the movement of the hand is in direct proportion to the pressure inside of the Bourdon tube.

Installation of Pressure Gages - Pressure gages are mounted on the instrument board as previously described, using, as a rule, the smaller of the two sizes of holes. From the pipe fitting (N, in Fig. II), a line of copper or aluminum tubing, usually 3/16" or 1/4" in diameter, is led to the proper connection on the engine. The locations of these connections are always shown on the installation drawings supplied by the manufacturer of the engine. The oil pressure connection is usually somewhere near the oil pump. The fuel pressure connection may be on the carburetor, or it may be on the relief valve assembly, depending on the fuel system installation. The connections to the instrument and to the engine or fuel system must be absolutely tight, particularly in the case of oil pressure gages, since otherwise the liquid will leak out. This is undesirable not only from the standpoint of "messing up" the power plant and causing a possible fire hazard, but also because a leak is likely to affect the accuracy of the reading on the gage. The pressure line must be installed without sharp bends and must be properly supported by some of the methods previously described in the sections devoted to the installation of fuel systems and other piping. If the oil pressure line is long, the instrument may read inaccurately in cold weather unless the line is filled with an oil of lighter grade than that used in the engine; for, since the oil in this line is not in circulation, it has no opportunity to be heated by the engine.

SUCTION GAGES

Suction gages are used with suction pumps which drive instruments operated by an air-jet, such as turn indicators, artificial horizons, etc. Some of these instruments use a Bourdon tube similar to that described in the paragraph above and others use an aneroid barometer. The second type is the more accurate. The suction is registered in inches of mercury. Fig. I shows a Kollsman suction gage. These instruments are installed just as the pressure gage.

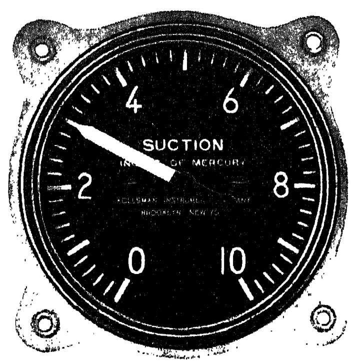


Fig. I

MANIFOLD PRESSURE GAGES

Manifold pressure gages are used to indicate the absolute pressure (or suction) in the intake manifold. As a rule, they are installed on airplanes equipped with engines of 200 h.p., or more, whether the engines are supercharged or not. The instrument is

Fig. I

desirable on unsupercharged engines, since when used in connection with the tachometer, it enables the pilot to determine how much h.p. is being developed. On supercharged engines, a manifold pressure gage is almost essential. These instruments may be obtained with various types of dials. Some of them are equipped with two hands, one of which is set to the desired manifold pressure while the other indicates the existing pressure. Others have part of the dial marked in red to indicate dangerous pressures. A third arrangement consists of two hands geared to each other with a ratio of 1 to 10, so that one hand moves entirely around the dial for each 10" of pressure while the other moves through one numbered division. The reading in all types, as in the case of the suction gage, is in inches of mercury. Fig. I shows a Pioneer manifold pressure gage of the simpler type, provided with a single hand and having the area of dangerous pressure marked with a red sector. This red sector is visible through a slot in the dial and may be set, prior to installation, to the figure recommended by the engine manufacturer. The setting on this particular instrument is made by inserting a screw driver in the slot at the end of the pinion shaft. The slot is made accessible by removing a screw located in the rear of the case opposite the pressure connection. After the setting is made, the screw must be carefully replaced, being sure that the lead gasket is installed, so as to make the case air-tight. If there is a leak, the instrument will not function correctly.

The principle involved in this instrument is the same as that employed in the altimeter. The line from the manifold to the instrument leads into an aneroid barometer. A suitable mechanism for operating the hand is attached to the diaphragm of this barometer.

The instrument is installed on the instrument board in the customary manner and a copper or aluminum line is led to the connection on the engine. The location of this connection varies with the different engines, but may be ascertained from the engine instruction book. Needless to say, the connections must be absolutely tight and the line must be properly supported and protected against chafing.

TEMPERATURE GAGES

Temperature gages are of two general types, the vapor and the electric. They are used to indicate the temperatures of the engine oil, the cooling liquid (in liquid-cooled engines), the carburetor air intake, the engine cylinders and crankcase, etc.

The Vapor Type Ten erature Gage - This instrument consists of an indicating head, a capillary tube, and a bulb. The instrument proper is simply an extremely delicate pressure gage of the Bourdon type. To the Bourdon tube is connected a number of feet of very fine tubing, terminating in a metal bulb which contains some volatile

material, such as ether. All joints are hermetically sealed, so that there is no possibility of the vapor escaping. When the temperature of the bulb is raised, the vapor inside expands and creates a pressure in the Bourdon tube. The face of the instrument is calibrated to read in degrees Fahrenheit or Centigrade instead of pressure units; for the expansion of the vapor, and hence the pressure inside of the instrument, is proportional to the increase in temperature. The vapor type temperature gage is never used for indicating extremely high temperatures, the limit, as a rule, being 212° F. or 100° C. Fig. I shows the dial of a Kollsman temperature gage, or

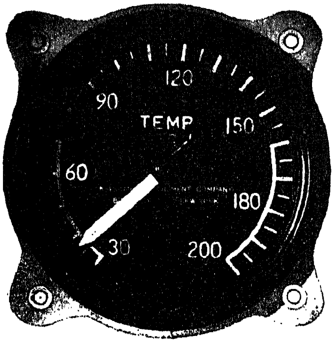


Fig. I

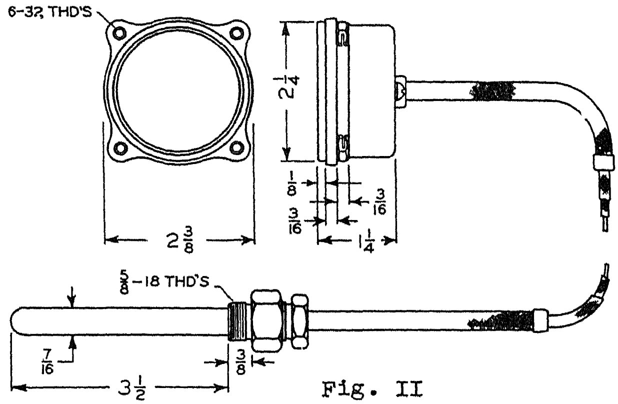


Fig. II

thermometer, and Fig. II illustrates the capillary tubing and the bulb.

Temperature gages may also be obtained in combination with other instruments. Fig. III shows a Kollsman Engine Gage unit which combines a temperature gage, an oil pressure gage, and a fuel pressure gage. Naturally, there are connections on the back of the case for all three instruments.

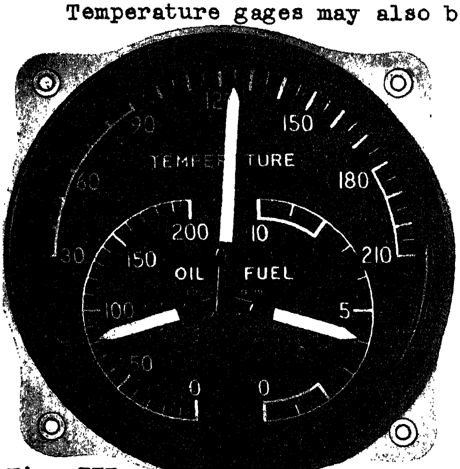


Fig. III

Installation of Vapor Type Thermometers - The installation on the instrument panel is entirely conventional, using the smaller of the cut-outs previously described. The particular caution to be observed is in the handling of the capillary tube. The instrument usually comes packed with this tubing coiled in the box. Great care should be taken in uncoiling it to avoid kinks or damage of any sort. The same care should be observed in leading the tubing from the cockpit to the engine, or wherever the bulb is installed. If possible, the instrument should be obtained with tubing of the exact length necessary. However, if the tubing is too long, the excess should be carefully wrapped into a coil of approximately 6" in

diameter. This coil should be wound with friction tape and should be supported so that it does not vibrate. The bulb is provided with threads to fit the thermometer connection on the engine, as may be seen in Fig. II. The end of the bulb to which the tubing is attached is hexagonal in shape. This section may be held with a wrench while the coupling nut is tightened, thus eliminating any likelihood of twisting the capillary tubing. Needless to say, if the capillary tube is cut or nicked, the instrument is ruined and can be repaired only by the manufacturer.

Electrical Resistance Thermometers - Resistance thermometers have several advantages over the vapor type. They are faster in operation; there is no capillary tube to be damaged, and if either the bulb or the indicator is injured, it can be replaced without replacing the remainder of the device; by means of a selector switch, the same indicator, or head, may be used to show temperatures at a number of different points; a greater range of temperature can be measured.

The principle involved, as the name implies, depends upon the variation of electrical conductivity, or resistance, with a variation in temperature. A standard resistance bulb is connected into one of the arms of a Wheatstone Bridge circuit, energized by the regular storage battery carried by most airplanes. The instrument, or indicator, is connected across the circuit so that the bridge circuit remains in electrical balance. A change in the temperature causes a change in the electrical resistance of the bulb, which upsets the electrical balance of the bridge circuit. The hand of the instrument will then move to the right or left, depending upon whether the temperature change is up or down. By calibrating the dial to read in degrees, the temperature can be accurately indicated.

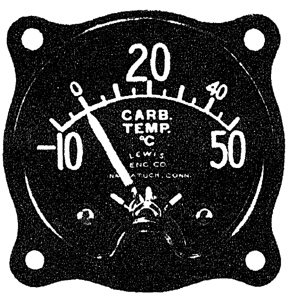


Fig. IV

Fig. IV shows a carburetor temperature indicator manufactured by the Lewis Engineering Company, and Fig. V shows the parts of a

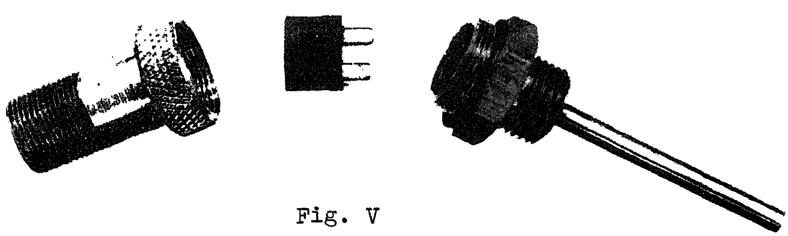


Fig. V

resistance bulb which screws into the same type of fitting as the vapor bulb. The wires are connected to the two prong plug shown in the center of Fig. V. The bulb shown is equipped for radio shielding,

the housing for which is shown to the left of the illustration.

The Thermocouple - Neither of the two types of thermometers previously discussed is suitable for measuring the temperatures attained by the cylinder heads and other parts of the engine. It is desirable to measure the temperature of certain points, as it is an indication of the functioning of the engine. For example, if the mixture is too lean, or if the cowling is not properly designed, the cylinder head temperatures may exceed safe limits; if lubrication is inadequate, the cylinder bases will overheat. To find the temperatures at such points, it is customary to use an instrument known as a thermocouple.

The principle of this instrument is based on the fact that when two dissimilar metals are brought into contact with each other, they will act as an electric generator and produce a definite electromotive force. This e.m.f. is constant with two given metals, provided the temperature of the metals remains constant. If the temperature changes, the e.m.f. also changes. This change may be measured by a sensitive galvanometer which is calibrated to read in degrees of temperature instead of in electrical units.

The complete thermocouple consists in general of a unit made of two dissimilar metals, usually iron or copper and constantan, held in contact with each other; electric cables leading from each of the metals; and an indicator, provided with terminals to which the cables are attached. In case it is desired to use one indicator for obtaining temperatures at a number of different points, the cables from the thermocouple lead to a selector switch and additional cables run from the switch to the indicator. By turning the switch

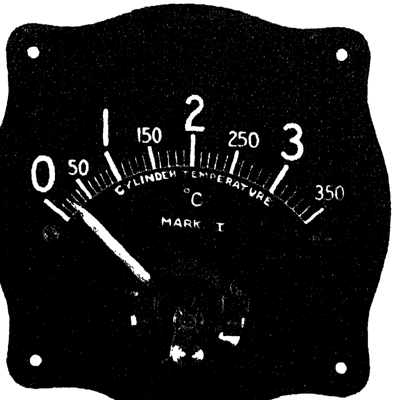


Fig. VI

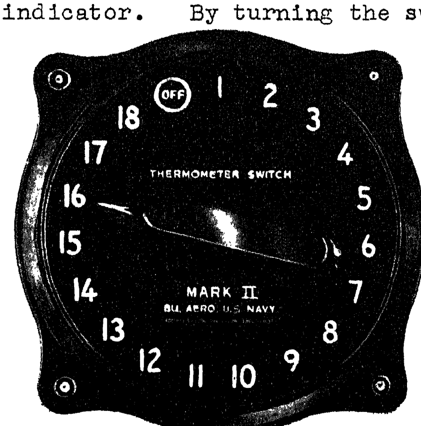


Fig. VII

to a given position, usually marked by a number, the temperature of the corresponding point on the engine will be shown on the indicator. An indicator manufactured by the Lewis Engineering Company is shown in Fig. VI, and an 18-point selector switch in Fig. VII. This switch provides for connections to the head and base of each cylinder of a nine-cylinder engine.

Connections to the engine are ordinarily made by means of a

gasket or a blind rivet. The gasket takes the place of one of the spark plug gaskets and hence is used for showing the temperature of the cylinder head. The blind rivet type of connection is used at the cylinder base or elsewhere on the crankcase.

<u>Installation of Thermocouples</u> - The indicator is mounted on the instrument panel just as any other instrument. The switch is ordinarily mounted beside the indicator, though it may be located at any convenient point. The blind rivet thermocouple is installed by drilling holes to fit the rivets (usually with a No. 31 drill) 1/8" deep and not more than 3/8" between centers. Copper rivets are forced into the holes and expanded by tapping steel pins which pass through them. The gasket type of thermocouple replaces the regular spark

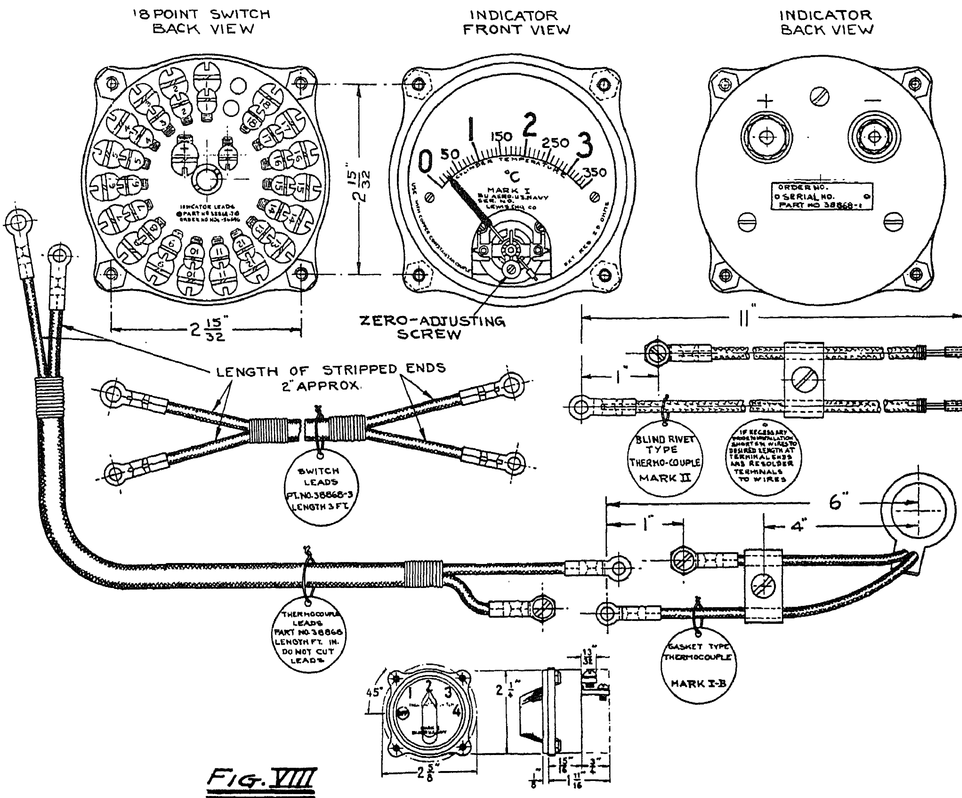


FIG. VIII

plug gasket. Before installing it, all grease or oil must be cleaned from the gasket seat at the spark plug hole and from the lower surface of the thermocouple gasket. The upper surface of the gasket should be coated with a thin film of grease so that the gasket will not be distorted when the spark plug is tightened. The thermocouples should be attached to the leads by means of machine screws and nuts of proper size. The indicator and switch are connected by means of a switch lead. One end of the lead is connected with the studs on the back of the indicator and the other end to the studs marked

"Ind. Lds." on the back of the switch. The back of the switch, the back of the indicator, and other installation information is given in Fig. VIII; also a four-point switch is shown at the bottom of figure. The thermocouple leads should then be connected to the switch studs which are stamped with numbers which correspond to positions on the front of the switch. Since the positive and negative studs are of different sizes, it is impossible to reverse the connections.

After the entire installation has been made, the switch should be turned to the "OFF" position. (If no switch is used, the indicator should be disconnected.) A reliable thermometer should be placed in the cockpit or cabin and sufficient time allowed for the thermometer to reach the cockpit temperature. The adjusting screw in the indicator glass is then rotated until the pointer indicates the temperature shown on the thermometer. After the adjustment is made, in the case of a system using no switch, the connections which were broken should be replaced. The leads should never be lengthened or shortened, since they are calibrated to a definite resistance. If it becomes necessary to trace leads from the engine end, a spare gasket type thermocouple may be attached to the leads in question and heated with a soldering iron or a match. The switch may then be tried in different positions until the indicator registers. In this manner the position of the leads on the switch may be readily determined.

In case more than 18 points on the engine are to be checked by one indicator, two switches will be necessary. In this case, obviously one or the other must always be in the "OFF" position.

FUEL LEVEL GAGES

The purpose of the fuel level gage is to indicate the amount of fuel in the tank. The simplest form of level gage consists of a cork or hollow brass float, to which is attached a rod. The rod extends through a hole in the tank and a red ball is mounted on the outside end of the rod. A tube of transparent material, usually of streamline shape, is fitted over the hole in the tank through which the rod projects, and encloses the end of the rod and the ball. As the level of the fuel changes, the float naturally moves up or down, as the case may be, and the ball moves with it. By noting the position of the ball inside of the transparent tube, the level of the fuel may be immediately ascertained. Gages of this type may be mounted under the tank where the tank is installed in the wing, or on top of the tank if it is installed in the fuselage. They are inexpensive and seldom give any trouble unless the float becomes saturated with the fuel. However, such gages can be used only when the transparent tube is visible to the pilot.

Another type of fuel level gage is electrically operated and is similar in general to those used on automobiles. There are a number of variations in detail design, the installation and operation of each being different. Before attempting to install or repair electric gages, full information should be obtained from the manufacturer.

The Hydrostatic Fuel Level Gage - Fig. I shows the cockpit

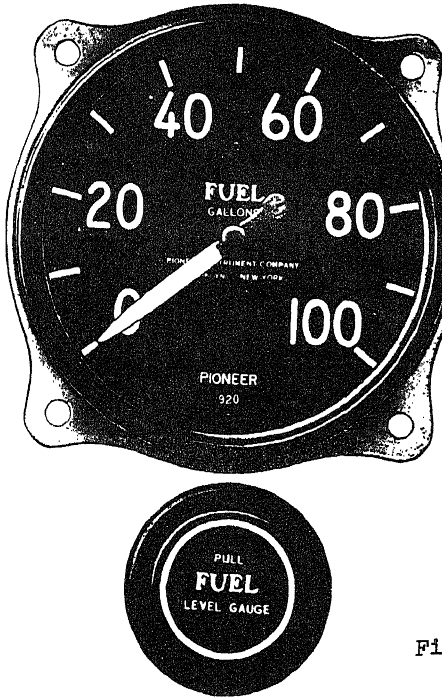


Fig. I

portion of a Pioneer Hydrostatic Fuel Level Gage. Its operation depends upon the principle that the pressure exerted by the volume of liquid is proportional to its depth. Fig. II is a diagram explaining the features of this gage. A cell, C, is mounted at the bottom of the fuel tank. Small holes in the bottom of the cell permit the fuel to pass from the tank to the inside of the cell. The top of the cell is connected by tubing to the inside of the diaphragm of a differential pressure gage. A small pump is connected into this tube line, between the diaphragm and the cell. From the upper portion of the instrument a tube is carried from the point at which the cell is vented, so that the pressure inside of the instrument case, but <u>outside</u> of the diaphragm, will be the same as the pressure inside the fuel tank above the level of the fuel.

When the gage is first installed, the tube which runs from the top of the cell, C, will, of course, be full of fuel up to the level of the fuel in the tank. The pump is operated and as air is forced into the line, the fuel is forced out until the cell, C, is full of air. The pressure which it is necessary to maintain on this air is obviously proportional to the depth of the liquid in the tank, and since this pressure is transmitted directly to the diaphragm, the diaphragm expands accordingly. Through the mechanism illustrated, this movement of the diaphragm is transmitted to the indicating hand. The face of the instrument is calibrated in gallons and is different for every installation, since obviously the movement from full to empty on a deep tank is much greater than on a shallow tank. For

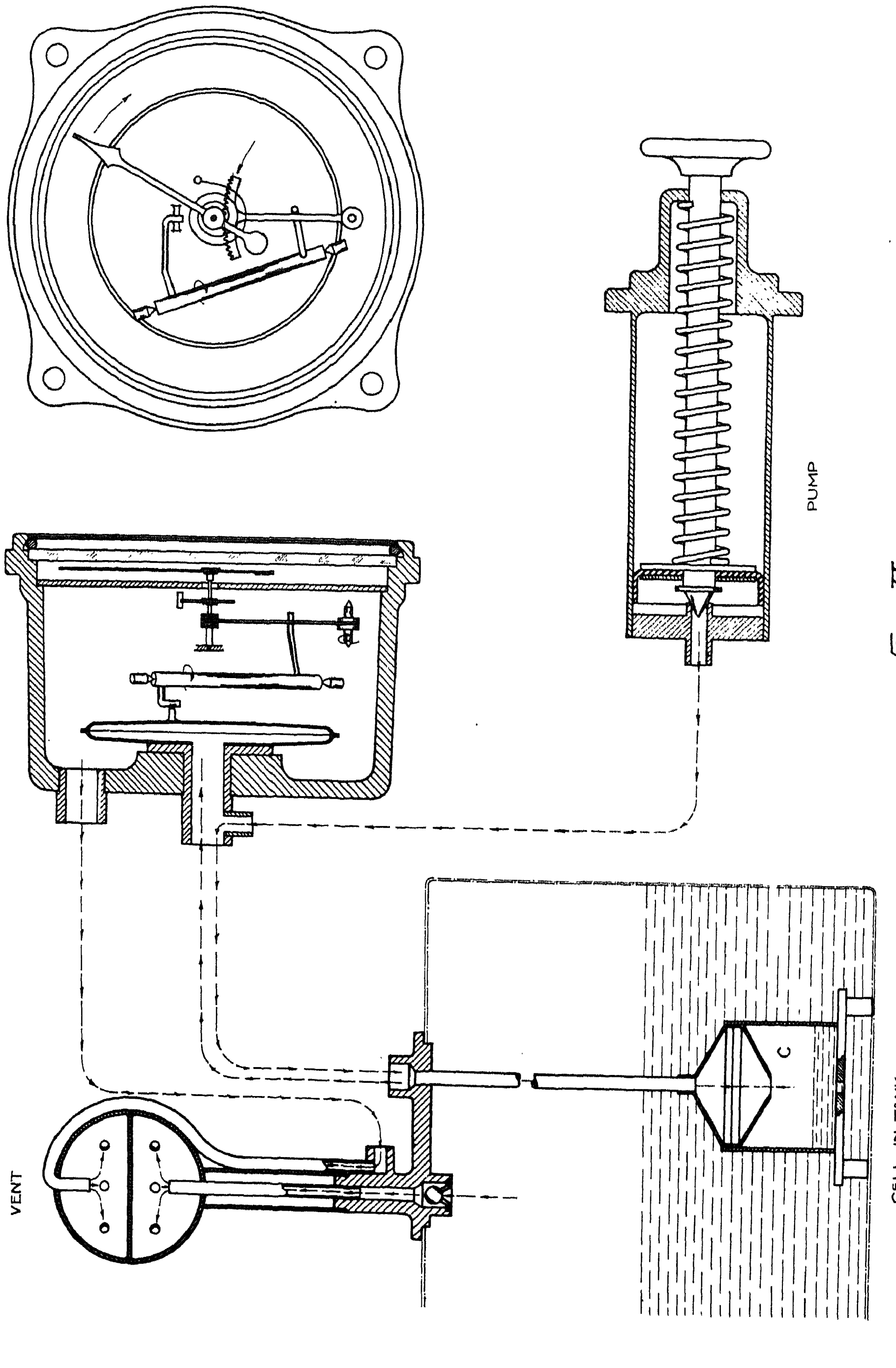


FIG. II

this reason the gage illustrated is not well adapted to extremely thin, flat tanks.

Changes in air pressure resulting from variation in elevation, in barometric pressure, or in temperature, cause the loss of small quantities of air from the cell, C. This air may be replaced at any time by operating the pump. The gage continuously shows the amount of fuel within the limits of the errors caused by the slight loss of air. The exact reading may be obtained by use of the pump and it is customary before taking an accurate reading to operate the handle of the pump by pulling and releasing it several times.

The installation of the indicator and the pump on the instrument board is the same as in the case of any other instrument. The pump is mounted in a hole 1-9/64" in diameter, held in place by screws, equally spaced on a circle 1-3/4" in diameter. Fig. III shows complete installation information with two types of cells. The cell at the left is the type used when it must be installed in a tank already built. The one shown at the right is built into the tank while it is under construction. Naturally, all joints must be absolutely airtight. When ordering a gage of this type, drawings of the tank and complete installation information should be given the manufacturer.

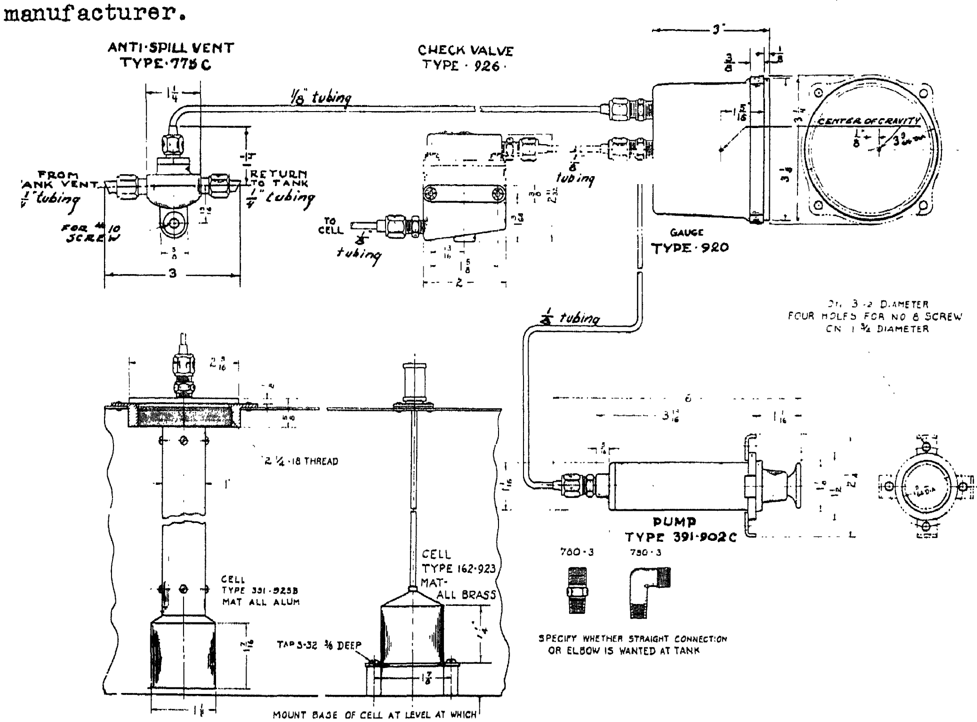


FIG. III

THE PRESSURE WARNING UNIT

Fig. I shows the front and side views of a Pioneer pressure warning unit. These units are designed to warn the pilot immediately

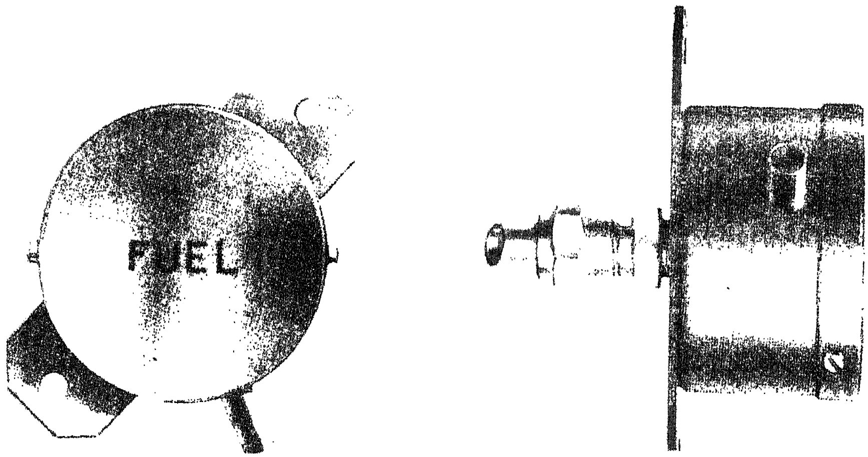


Fig. I

of any drop in the pressure or vacuum system. They have found an important place on multi-engine planes where the pilot has so much to watch that he can give only intermittent attention to instruments not in the flight group.

The mechanism in these units is similar to that of a sensitive pressure gage of the corrugated diaphragm type. However, there is, in addition, an electrical contact, one side of which may be connected through a 12-volt battery to a suitable warning device, such as a light, buzzer, horn, or any other means of attracting the pilot's attention. Usually a red light is used for the warning signal. If the fuel or oil pressure should drop below the safe minimum or if the vacuum system fails to function properly, the red light goes on and attracts the attention of the pilot to the system which is not functioning properly.

As may be seen from Fig. I, the unit is mounted on the instrument board by means of two screws. The line extending from the rear of the instrument is connected into the pressure line on the system for which the indicator is intended, that is to say, fuel, oil, or vacuum. Electrical connections lead through the tube extending from the side of the instrument.

THE EXHAUST GAS ANALYZER

Fig. I shows an exhaust gas analyzer manufactured by the Cambridge Instrument Company, Inc. The device illustrated in this figure is intended for use on a single engine airplane. Fig. II shows the indicator unit used on a four-engine airplane. Four analysis

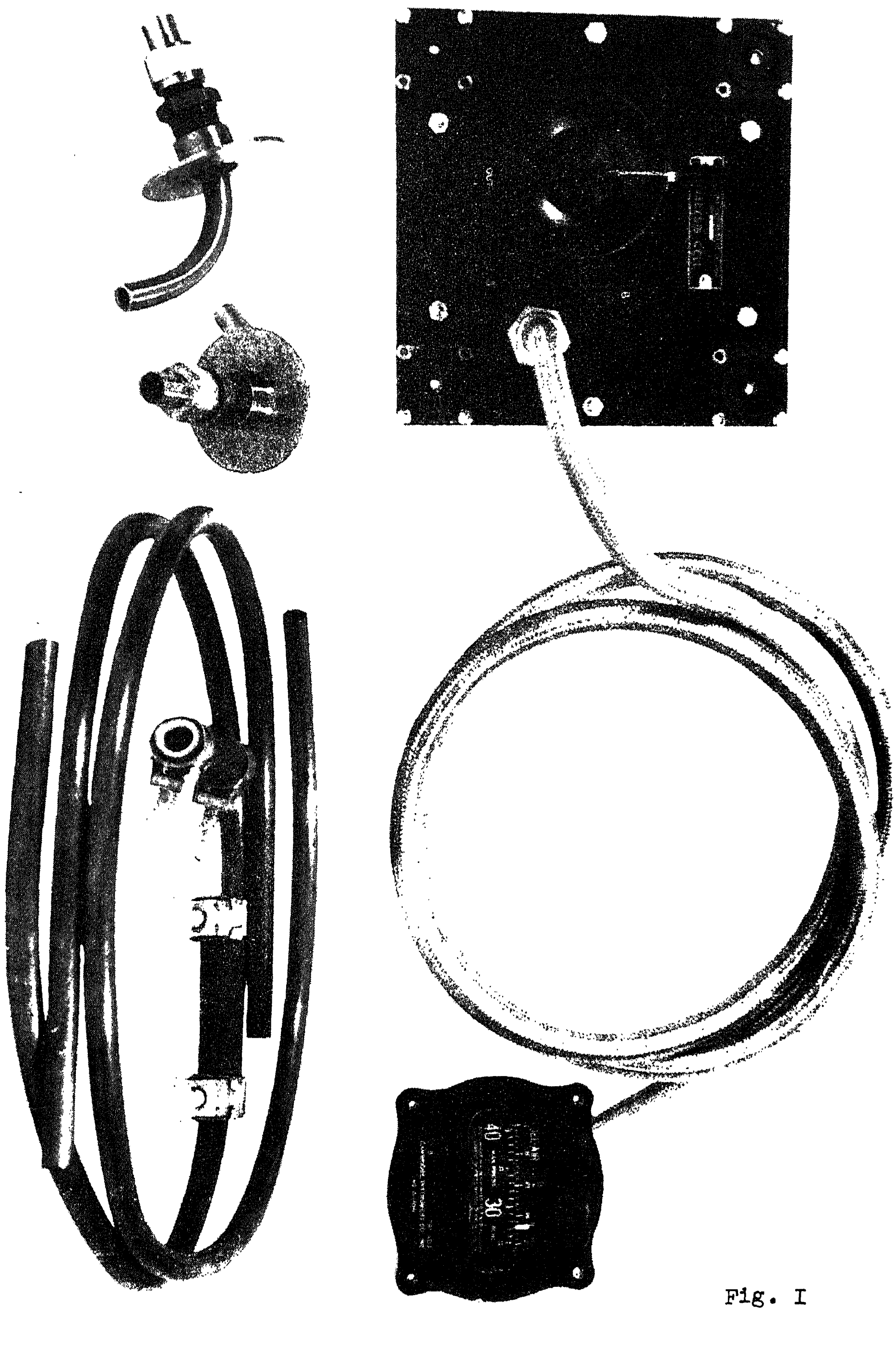


Fig. I

cells, one for each engine, are required in the latter installation. The following description of the instrument is quoted from the literature of the manufacturer.

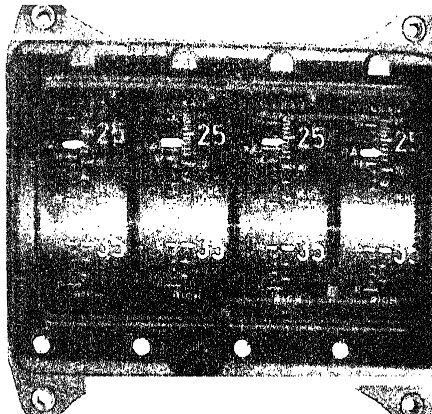


Fig. II

"The Cambridge Aero Mixture indicator, designed as a flight instrument for aircraft, analyses the exhaust gas from the engines and shows the result of this analysis on an indicator scaled in terms of Fuel-Air Ratio over a range of .11 to .066. In addition to the fuel-air ratio figures there is provided a scale upon which appears manifold pressures, the scales being so related as to indicate the optimum mixture ratio for a given manifold pressure. Such a second scale can be had only when the correlation data between manifold pressures and fuel-air ratios is available for the particular engine with which the instrument is to be used.

"With this instrument the pilot has continuously before him an accurate indication of the mixture ratio, whether near sea level or at high altitudes, and with this guide can correctly set the mixture controls. The accuracy of this method renders obsolete the older and less accurate practice of using the engine tachometer and head temperature pyrometer as guides in adjusting mixture controls. With the advent of the automatic variable-pitch, constant-speed propeller, the tachometer indication is no longer useful and it becomes absolutely necessary to provide other means of indicating mixture ratios.

"The advantages of the Aero Mixture Indicator can briefly be summed up as follows:

(a) Ability to obtain best performance of engines under any given set of conditions.

(b) Maximum economy in gas consumption.

(c) Economy in gas permits an increase in pay load since a smaller fuel supply is required.

(d) Safety factor in event of emergency when fuel supply is low, the instrument enabling the pilot to fly the maximum length of time with the remaining fuel.

(e) Protection against the possibility of damage to engine which might be caused by operating with too lean a mixture.

(f) A continuous check on operation of automatic carburetors

"Operation of the instrument is based on the well known thermal conductivity principle wherein four platinum spirals forming the four arms of a Wheatstone bridge circuit are employed, two being exposed to the gas under test and two being exposed to a gas of known heat conductive capacity. The known or 'standard' gas in this instance is moisture saturated air which is contained in the small chambers where the 'comparison' spirals are located. The spirals are heated a definite amount by an electric current and they will remain in balance as long as they are surrounded by similar gases and thus are at like temperatures. However, when the 'test' spirals are exposed to the exhaust gas, the bridge will become unbalanced resulting in a deflection of the galvanometer pointer to an extent comparable with the variation in the constituents of the gas and in this manner it is possible to determine the mixture ratio directly."

The illustration in Fig. I shows the parts necessary for the installation, including nipples which are attached to and extend inside of the exhaust pipes, copper tubing to conduct the exhaust gas to the analysis cell, and rubber hose connections for the joints between the tubing and the nipples, as well as between the tubing and the analysis cell. The exhaust gas is led to the pipe marked "IN" and from the pipe on the cell marked "OUT" is led to the outside of the airplane.

"The analysis cell is mounted adjacent to the engine so that a sample of the exhaust gas can readily be obtained and passed through the cell by way of the inlet and outlet pipes provided. It is in the cell that the Wheatstone Bridge is located. The cell is shipped with the cable already attached and this cable is provided with a quick detachable plug for connecting to a socket on the back of the indicator unit. There is another socket and plug on the back of the indicator unit for the current supply for instrument operation. The indicator unit, of the standard size of 3-1/8", is placed in the instrument panel where it may be easily observed by the pilot. It is provided with individual lighting, luminous scale, and automatic current regulation so that no adjustments are ever required in this respect. Furthermore, no switches or controls are required, the instrument being connected to the regular instrument current supply line, thus relieving the pilot of all operating duties. The instrument can be provided for operation on either 12 or 24 volts D. C.

When ordering this instrument the manufacturer and model of the engine, the octane rating of the fuel, the electrical current available, and the length of the cable required to connect the indicator unit to the analysis cell should be specified. The installation is extremely simple and little or no maintenance is required. However, complete instructions are furnished by the manufacturer with each instrument and should be consulted.

While the Aero Mixture Indicator is a highly desirable aid in the operation of any aircraft, it becomes essential to the operation of high-power, high-performance engines from the standpoints of both safety and economy. Thousands of commercial transports and military planes throughout the world are so equipped.

CHAPTER 13
PROPELLERS

The installation, maintenance and repair of the modern types of propellers is, for the most part, the work of a skilled specialist. Even the assembly to the crankshaft of a constant speed or hydromatic propeller is a more or less complicated procedure not within the scope of the ordinary mechanic's duties. On the other hand, any engine mechanic should be able to mount a wooden or a constant pitch metal propeller and to perform routine inspection and maintenance on the blades, and other exterior parts, of any model. He should also understand something of the general theory of propellers and the principles of operation of the controllable and constant speed types. Accordingly, this chapter is devoted to a brief discussion of propeller theory, an explanation of the mechanisms of the controllable varieties, and instructions for ordinary service on fixed and adjustable pitch models. The maintenance of the more complicated types is not discussed and should not be attempted except in a regular propeller service station.

PROPELLER NOMENCLATURE

In order to understand a discussion of propeller theory the various parts and aerodynamical terms should be understood.

Propeller Parts

Blade - One arm or limb of a propeller from the center to the tip. Propellers are made with two, three or four blades.
Blade back - The surface of the blade which corresponds to the top surface of an airfoil, or, the surface toward the front of the airplane.
Blade face - The surface of the blade which corresponds to the bottom of an airfoil, or the surface toward the rear of the airplane.
Boss - The thickened center portion of a propeller, ordinarily used in reference to wooden propellers.
Hub - In a wooden propeller, the metal mounting used for attaching the propeller to the engine crankshaft. In a metal propeller, the central portion which is fitted to the crankshaft and which carries the blades.
Hub nut - The nut which locks the hub to the crankshaft. Strictly speaking, it is a part of the engine rather than of the propeller in most cases.
Root (of the blade) - The thickened portion of the blade near the center.
Spinner - A fairing, roughly conical or semi-ellipsoidal in shape, fitted to the propeller boss and revolving with it. It was once thought that spinners improved performance, but they are seldom used today.
Tip (of the blade) - The portion of the blade furthest from the center.
Tipping - A covering, usually of brass, monel metal or stainless steel, over the blade tips of a wooden propeller to prevent damage from gravel or spray.

Description and Aerodynamical Terms.

Blade angle - The acute angle between the chord of a section of the blade and a plane perpendicular to the axis of rotation. See Fig. I.

Blade area - The developed area of the blade face exclusive of the boss and the root, or, in other words, the area of the effective portion of the blade. The propeller area is the area of one blade times the number of blades.

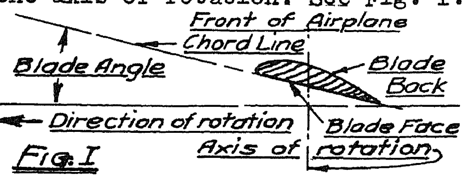


Fig. I

Diameter - The diameter of the circle described by the tips when the propeller is revolving. In other words, the length of the propeller from tip to tip.

Disk - The circle described by the tips when the propeller is revolving.

Efficiency (propeller) - The ratio of the thrust power to the power delivered by the engine. Not to be confused with propulsive efficiency.

Interference - The effect upon the action of the propeller by objects too near the effective portion of the blade.

Pitch - Effective pitch is the distance an airplane advances along its flight path for one revolution of the propeller. Geometric pitch is the distance that any element of a blade would advance if it were moving in a solid medium, or if there were no slip.

Section (of blade) - Any cross section of the propeller blade in a plane parallel to the axis of rotation.

Slip - The difference between the effective pitch and the geometric pitch.

Slipstream - The stream of air driven back by the propeller.

Thrust - The force exerted by a propeller in a line parallel to its axis of rotation.

Track - The path of the blade if rotated with the airplane stationary. If the blades "track", each will follow the same path.

PROPELLER THEORY

Generally speaking, the airplane propeller is simply a series of rotating airfoils. When it is turned by the engine, air is driven back and the reaction of this air tends to pull or push the ship ahead (if the propeller is of the tractor type, mounted ahead of the engine, the effect is one of pulling; whereas if it is mounted behind the engine, as a pusher, its effect is to push the airplane forward). Propellers are made with one, two, three or four blades. The two-blade type is the most common except in the case of large transports and bombers, on which three-bladed propellers are almost universally used.

Each section of a propeller blade is a carefully designed airfoil. The sections near the tips travel at a higher speed than those near the hub; hence the blade angles become less toward the tip. The sections near the center, or root, of the blade move at a comparatively low speed and are commonly much thicker and built at a greater angle than those of the outer portion. The greater thickness is necessary to enable the blade to withstand the stresses occurring in this region. With the exception of the portion very near the hub, each section of the blade is designed and set at such an angle that

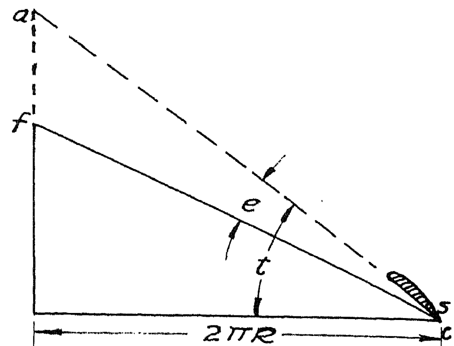


FIG. I

when the propeller is being operated at a given r.p.m. and forward speed, the highest efficiency of the section will be obtained. This means that every propeller must be designed for a given h.p., a given r.p.m., and a given translational velocity (which, in simple terms, is simply the speed of the airplane). Hence, a propeller designed for one airplane is not likely to produce full efficiency on another. Furthermore, if the pitch of an adjustable propeller is changed from that of the original design, a certain amount of efficiency will be lost. However, this loss is small unless the change in pitch has been considerable.

The angle at which each section meets the air in flight is much less than the actual blade angle of the section, due to the fact that the propeller is moving forward as well as rotating. This is illustrated graphically in Fig. I. The circumference of the circle through which the section of the blade s moves is shown as a horizontal line, c - c'. The length of this line is, of course, the circumference of the circle with a radius equal to the distance of the section from the center line of the propeller or propeller axis. If this distance or radius is designated by the letter R, the length of the line is, of course, $2\pi R$. The distance which the airplane, and consequently the propeller, moves forward while the propeller is making one revolution is indicated by the vertical line c - f. This is the effective pitch. The true blade angle is the angle between the projected chord line, c - a, of the section, and the horizontal line, c - c'. This angle is designated by the letter t. The effective blade angle, e, is the angle between the projected chord line and the line c - f, which represents the actual path of the blade section. The distance from f to a represents the slip as a linear dimension. A study of the diagram will show that the smaller the distance travelled (c' - f) during one revolution, the greater will be the slip (f - a) and consequently the lower the efficiency of the blade. Obviously, then, for best efficiency, if the airplane is moving slowly, the pitch, or blade angle, should be low; whereas, if the speed of the airplane is high, the pitch should also be high. This fact should be clearly understood and remembered in the discussion of controllable and constant speed propellers.

A propeller must be capable of withstanding severe stresses, which are greatest near the hub. These are caused by centrifugal force, which tends to pull the blades away from the hub, and by the thrust, which tends to bend the blade forward. Hence, the rear side of the blade is subjected to tension from the centrifugal force plus additional tension from the bending. It is for this reason that any nicks or scratches in this portion of the blade may cause very serious consequences. The stresses mentioned increase in proportion to the square of the r.p.m. In other words, if the r.p.m. of the propeller is doubled, the stresses are increased according to the square of 2, or 4 times. It is extremely difficult to calculate the

stresses involved with any degree of accuracy. Accordingly, new types of propellers are usually subjected to a destruction test in which the propeller is whirled by a powerful electric motor to a much higher speed than any it will encounter in actual use. Such testing can be done only in specially equipped testing laboratories where proper safety precautions have been taken; for, if a propeller breaks under test the blades are thrown off with the speed of a rifle bullet. As an indication of the strength required, it may be mentioned that the blades of some metal propellers are designed to withstand a tension at the hub of 300,000 lbs.

A propeller must be designed not only to withstand the stresses just discussed, but must also be rigid enough to prevent what is known as <u>fluttering</u>. Fluttering is a type of vibration in which the ends of the blade twist back and forth at high frequency, the twisting being around an axis perpendicular to the engine crankshaft. It is accompanied by a distinctive noise, often mistaken for exhaust noise. This constant vibration tends to weaken the blade and may eventually cause failure. Failure of a propeller blade in flight is certain to wreck the engine, no matter how quickly the switch is shut off, and in several cases has been known to throw the engine completely out of the airplane.

Propellers of relatively large diameter, and consequently turning at comparatively slow speed, are more efficient and much more quiet than smaller propellers turning at higher speed. This is one of the arguments in favor of geared engines, since the rotational speed of the propeller can be kept relatively low while the r.p.m. of the engine is relatively high. This combination produces good propeller efficiency and high h. p. at the same time.

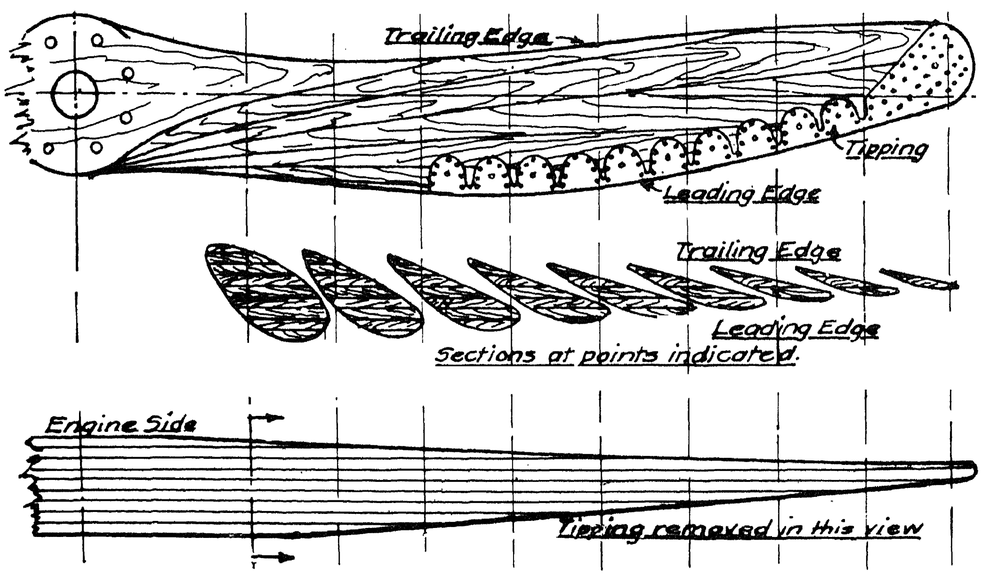
TYPES OF PROPELLERS

Propellers may be divided into two main groups, the wooden and the metal. Various other materials, such as micarta, have been used to a limited extent, but are seldom found in modern aircraft. Metal propellers are sub-divided into a number of different varieties, each of which will be discussed in detail below.

WOODEN PROPELLERS

The first propellers used were made of wood and for many years no other material was employed. Wooden propellers are used widely today on engines of less than 300 h.p., but are seldom found on the larger engines. They have the advantage of being much less expensive and much lighter than any of the metal types. It is also claimed by many that they are more efficient on the smaller varieties of sport airplanes, particularly in the case of seaplanes. Their disadvantages are that they are affected to some extent by climatic conditions, temperature, humidity, and the like, and that they can seldom be satisfactorily repaired in case of any but very minor damage. Also, because they are lighter and hence have less flywheel effect, most engines do not run quite as smoothly with wooden propellers as they do with those made of metal.

Wooden propellers are made of a number of laminations approximately 3/4" to 1" in thickness, glued together under high pressure



TYPICAL WOODEN PROPELLER

with waterproof glue. The reason for this laminated construction is to eliminate warping as much as possible. After the glue has set, the propeller is roughed out to approximate dimensions on a machine known as a propeller lathe, after which it is allowed to hang for a week or more so that the moisture content of the laminations will become equalized. It is then carved by hand to its exact dimensions

and the tipping and protective coatings applied.

The wood from which propellers are made is ordinarily kiln dried until its moisture content is very low, usually between 5% and 7%. The most popular wood for propeller manufacture is birch, although oak, walnut, mahogany and other woods are sometimes used. Propellers have also been made from a combination of woods, alternate laminations being spruce, or some such soft wood, and walnut or mahogany, on the theory that soft and hard wood may be glued together better than two pieces of hard wood.

The wooden propellers for commercial use are ordinarily protected with a number of coats of clear varnish. Those intended for military airplanes are usually first painted with aluminum enamel and finished with colored enamel, maroon for the Army and gray for the Navy. Another protective coating consists of aluminum foil applied on "tacky" varnish with a final application of the colored enamel just described. However, few military ships use wooden propellers.

THE ONE-PIECE METAL PROPELLER

The first metal propeller was invented by the late Dr. S. A. Reed and developed by the Curtiss Aeroplane & Motor Company. It consisted of a flat slab of duralumin, about 3/4" thick, twisted to the proper pitch and provided with wooden bosses at the center, to which the metal hub was bolted. This type of propeller has been discontinued.

The modern Curtiss one-piece propeller is made of forged duralumin and is similar in general appearance to a wooden propeller except that the sections are much thinner. It is provided with a steel insert at the center, two types of inserts being provided, one to fit engines with tapered crankshafts and the other to fit spline shafts. Cross-sections of the two types of hubs will be shown later in the section devoted to "INSTALLATION OF PROPELLERS." An illustration of the complete propeller is given in Fig. I. The manufacturers claim the following advantages for this type of propeller: light weight, due to the one-piece construction and the consequent elimination of heavy attachments at the root of the blade; low maintenance cost, also due to the one-piece feature; efficient cooling for radial engines, because of the thin section at the root of the blade; high ground

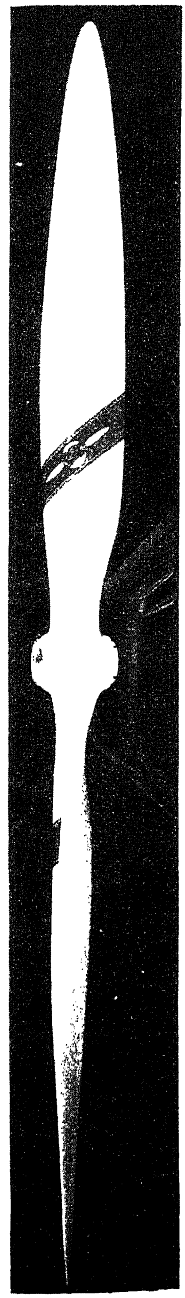


FIG. I

r.p.m. in proportion to the flight r.p.m., thus improving take-off; high aerodynamic efficiency and smooth operation.

Although there is no joint between the blades and the hub, the pitch of the one-piece Curtiss propeller can be changed, within reasonable limits, by any properly equipped propeller service station. This change is accomplished simply by twisting the blade slightly and may be done without heat treatment. The same applies to repairing the blades when they have been slightly bent in an accident. The extent of the damage which it is permissible to repair will be discussed later under "MAINTENANCE OF PROPELLERS."

THE HAMILTON STANDARD ADJUSTABLE PITCH PROPELLER

A two-bladed Hamilton Standard adjustable pitch propeller is illustrated in Fig. I. This type of propeller is also made with three or four blades. The particular features of the design are that the angle and consequently the pitch of the blades can be adjusted on the ground by rotating or twisting them in the hub and that individual blades can be replaced at any time in case of damage.

The blades of the Hamilton Standard Propeller are made of forged aluminum alloy. The hub is made of steel, drop-forged and machined to exact dimensions. The hub is made in two halves held together at the ends by clamping rings. The component parts of the hub may be seen in Fig. II, which shows one clamping ring in position and one disassembled.

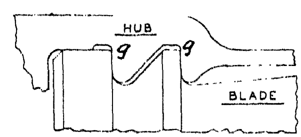


FIG. II-B

The root of the blade is round, which gives it its adjustable feature. It is provided with shoulders or flanges which fit into grooves, g, provided in the hub. See Fig. II-A and II-B. Certain models of this propeller have only one shoulder and one groove instead of two. These shoulders prevent the blade from being pulled out of the hub by centrifugal force. The

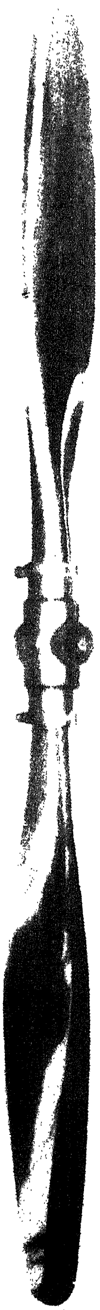


FIG. I

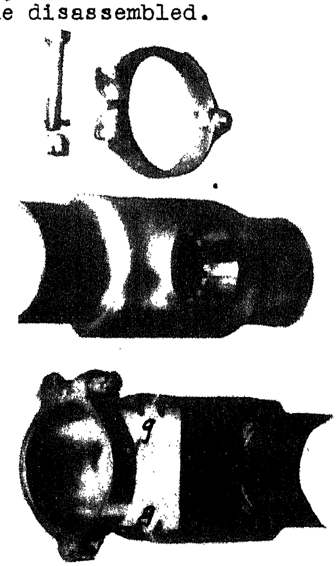


FIG. II-A

blades are kept from twisting and thus changing the pitch by the tight grip of the clamping ring.

The blades of this propeller cannot be adjusted in flight and should be set by the factory or a propeller service station. However, in an emergency, they can be set by any mechanic.

HAMILTON STANDARD CONTROLLABLE PITCH PROPELLER

The Hamilton Standard Controllable Pitch propeller may be adjusted to either of two positions while in flight. The low pitch position is used for take-off and steep climbs. The reason for the desirability of a low pitch while taking off has been explained in the preceding section, "PROPELLER THEORY." The high pitch position is used for cruising and high speed operation. The propeller is set to the desired position by means of a control located on the instrument board or elsewhere within easy reach of the pilot. The principle of operation is illustrated by Fig. I and Fig. II and is explained in the following paragraphs, which are quoted from the Service Manual of the manufacturers.

"The Hamilton Standard Controllable Propeller in its present form represents years of intensive development of the hydraulic principle of operation. This method was selected because it offered a positive means of control with a minimum number of parts; light weight with simplicity of construction; high dependability with long life. The control forces are carefully calculated so as to be ample for the purpose, with no possibility of reaching sufficient magnitude to break any of the parts.

"In operation, the engine oil pressure is used only to move the blades into the low pitch position. The blades are shifted to the high pitch position by means of centrifugal counterweights which are attached directly to the blade ends.

"An oil-pressure line from the main pressure supply in the engine is conducted to a three-way valve and thence, through a collector ring, into the interior of the front end of the crankshaft and out into the pitch-operating cylinder. The three-way valve is so arranged that rotation of the valve stem will cause the oil line leading to the propeller to be connected with the pressure supply in one position or with a drain directly into the crankcase in the other position. When this oil valve is thrown into the pressure supply position, the oil flows through the collector ring into the crankshaft and out into the cylinder, causing the cylinder to move forward on the piston.

"As the cylinder moves forward the counterweight bearing shaft, which is attached to the base of the cylinder, moves in the cam slot of the counterweight bracket. This bracket is attached to the blade bushing by means of index pins. As the bearing shaft moves up the cam, it causes the bracket to turn. This turning of the bracket is transmitted to the blade, rotating it to the low pitch position.

"When the three-way valve is turned to the 'drain' position, the oil pressure on the cylinder head is released. On the arm of

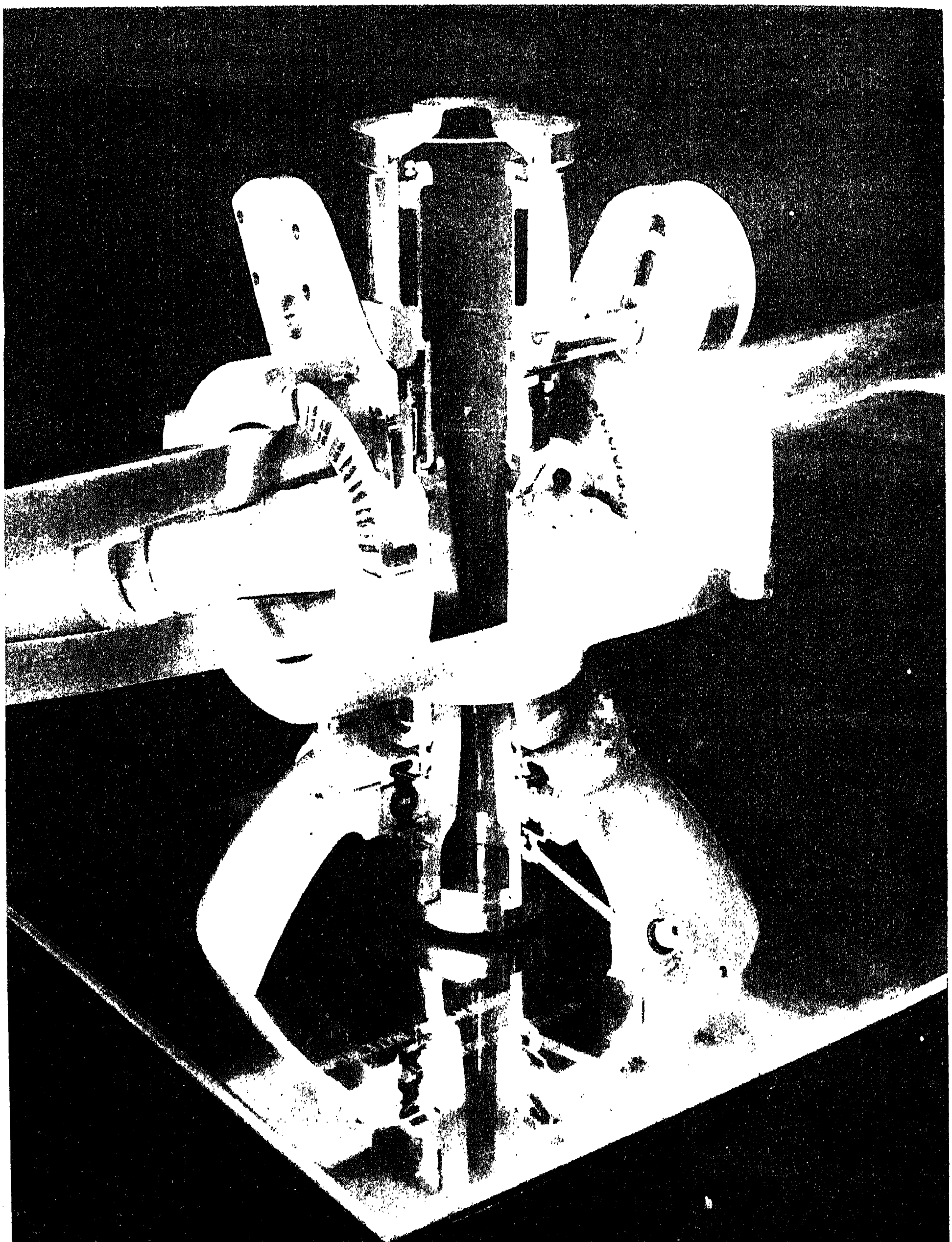


FIG. I

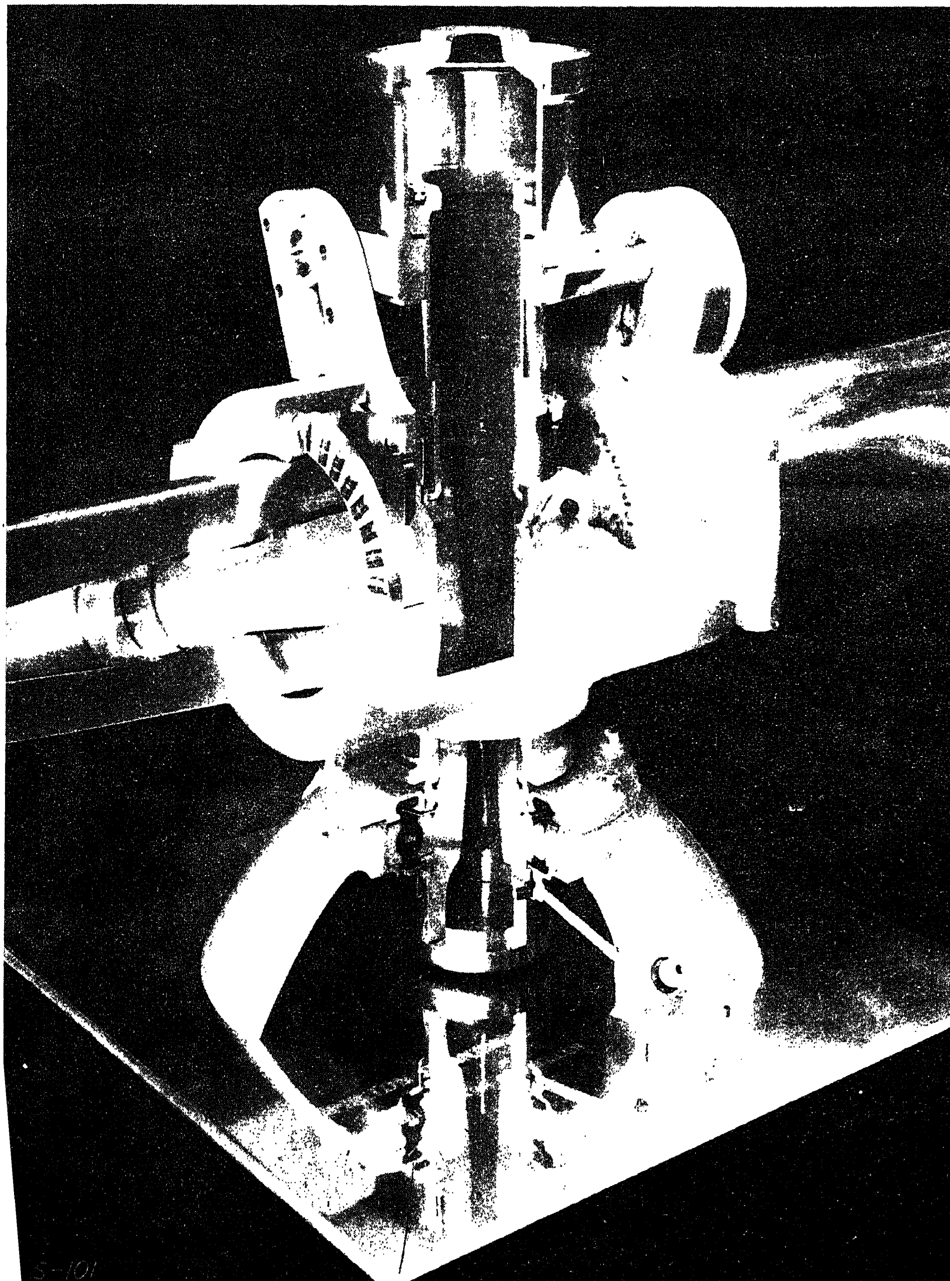


FIG II

each blade bracket is a counterweight. The centrifugal force generated by these counterweights turns the brackets and rotates the blade to the high pitch position.

"Most of the later high powered American engines incorporate a built-in valve as standard equipment. This permits ready installation of the Hamilton Standard Controllable Pitch Propeller. Adaptations of other engines have been worked out in cooperation with the engine manufacturers. If it is desired to install a controllable propeller on an engine not incorporating the valve, the engine manufacturer should be consulted.

"The action of the hydraulic and counterweight controls is such that extra force is available for movement into low pitch, when the revolutions are below the normal value, and extra control forces are available for going into high pitch, when the revolutions are above the normal value."

HAMILTON STANDARD CONSTANT SPEED PROPELLER

The improved efficiency obtained by the use of a constant speed propeller, with particular respect to climb, is indicated in the diagram shown in Fig. I. This diagram also shows the improvement gained by the use of the two-position controllable propeller as com-

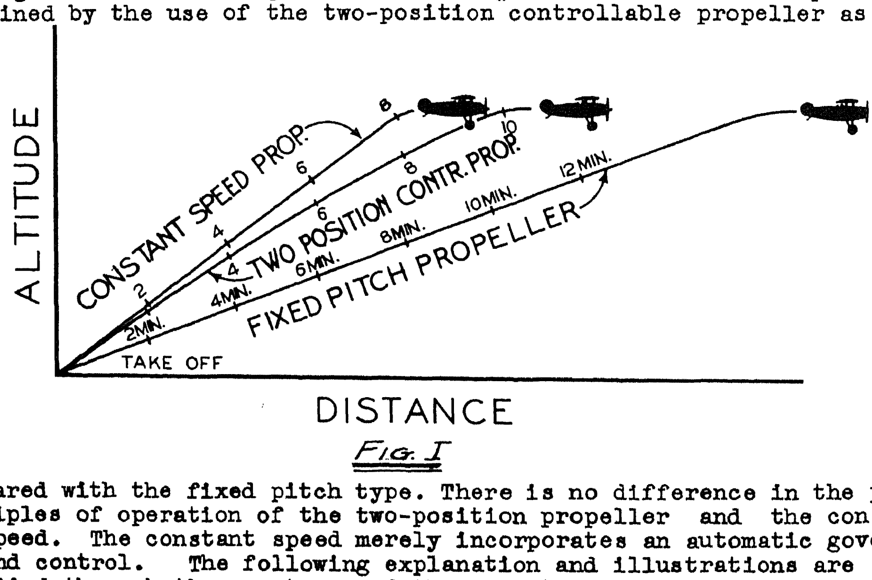


FIG. I

pared with the fixed pitch type. There is no difference in the principles of operation of the two-position propeller and the constant speed. The constant speed merely incorporates an automatic governor and control. The following explanation and illustrations are supplied through the courtesy of the Hamilton Standard Propeller Company:

Principles of Operation - "As is well known, the primary function of any constant speed propeller is to permit the engine to run at desired r.p.m. regardless of altitude or forward speed of the airplane. This is important not for propeller performance but for engine operation, since power depends on both the r.p.m. and the throttle opening. The constant speed propeller makes possible the control of engine speed independent of the throttle. From one

standpoint it acts as a governor holding r.p.m. constant no matter whether climbing, diving or flying level. From another standpoint it acts as a controllable load, permitting the engine to develop as much of its full rated power as the pilot wishes.

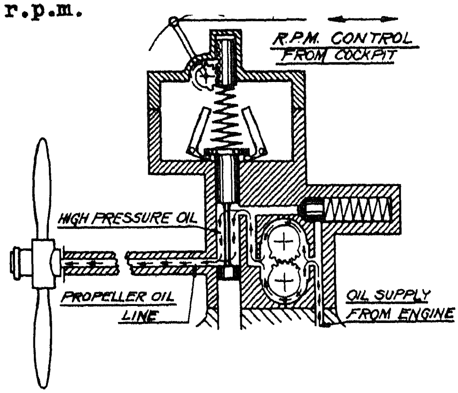
"This is accomplished by automatic change of propeller pitch. In the Hamilton Standard design the pitch is shifted by oil pressure, the propeller itself being basically the same as the Hamilton Standard two-position controllable. Counterweights acted on by centrifugal force provide the operating force to move the blades toward high pitch, and the oil pressure works in the opposite direction against the counterweights, setting the pitch to any intermediate position between full low and full high.

"Pitch is automatically selected by a separate unit called the Constant Speed Control which regulates the oil pressure in the propeller operating cylinder. A simple gear pump in this unit boosts the engine oil pressure up to 180-200 lbs. per square inch where it is maintained by means of a relief valve. Although considerably less pressure is normally required to shift pitch, this comparatively high value is desirable to give responsive pitch changing action when called for by the constant speed control. It provides better governing and eliminates over-reving and under-reving which might result from sluggish action.

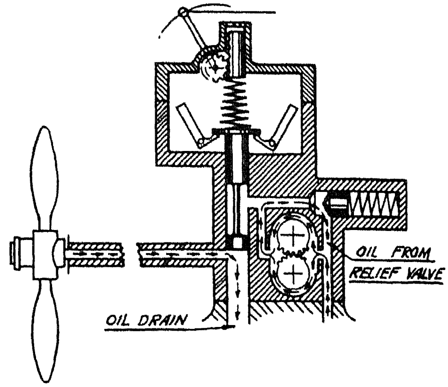
"The sketches in Fig. II indicate propeller, constant speed control, and booster pump in their associated relation for three different operating conditions. The first, 'Underspeed', is the case where r.p.m. is less than that desired, such as occurs momentarily when the airplane is pulled up into a climb, or when the throttle is moved to a partially closed position. The second, 'Overspeed', is the case where r.p.m. is more than that desired, such as occurs momentarily when the plane is nosed down into a dive, or when the throttle is opened rapidly. In the third case, 'On Speed', the r.p.m. is exactly the amount for which the control is set and there is no need to increase or decrease the propeller pitch.

"In the speed control a pilot valve moves up and down in a cylinder in response to the action of fly weights working against the tension of a spring referred to as the 'r.p.m. Spring'. The fly weights are driven by the engine in proportion to engine speed; the tension of the spring is controlled by the pilot. Obviously the greater this spring tension is, the faster the fly weights must rotate before they can compress the spring upward. When they are not rotating fast enough to accomplish this, the spring forces the pilot valve downward so that it uncovers the port leading to the propeller feed line as shown in the 'Underspeed' sketch. This allows oil under pressure from the booster pump to flow to the propeller, decreasing its pitch. When the fly weights are rotating faster than the speed for which the spring tension is set, they compress the spring, carrying the pilot valve upward, opening the propeller port and allowing the oil in the propeller cylinder to drain back to the engine. This shifts the propeller toward high pitch as shown in the 'Overspeed' sketch. The 'On Speed' condition results when the rotation of the fly weights is just sufficient to balance the spring tension and

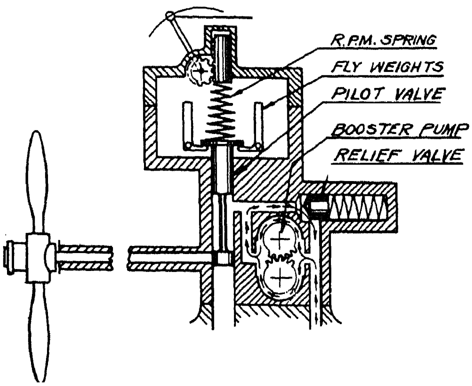
hold the pilot valve so that it closes the propeller port. Under these conditions the pitch remains constant. This is the stabilized condition in which the pitch is exactly right to give the desired r.p.m.



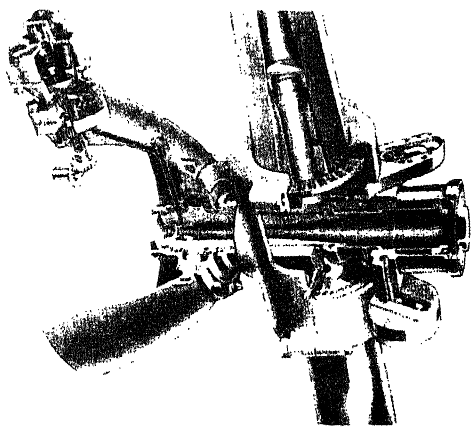
UNDERSPEED—High Pressure Oil Enters Propeller Line To Decrease Pitch



OVERSPEED—Oil Drains from Propeller To Increase Pitch



ON SPEED—Pilot Valve Closes Propeller Line To Maintain Pitch



Cut-away View of Constant Speed Propeller Installation

FIG. II

"The booster pump is a simple gear type driven by the engine. Oil from the engine pressure system feeds into it and is boosted to higher pressure. This high pressure oil fills the space between the necked-down section of the pilot valve and the walls of the cylinder, and backs up against the spring-loaded relief valve. When the pressure builds up to about 180 lbs./sq.in. the relief valve opens allowing some of the oil to circulate around the pump and come back into it again on the low pressure side, the same oil being used over and over without drawing on the engine lubricating supply. Only when the pilot valve moves downward as shown in the 'Underspeed' sketch does any of the oil flow out to the propeller, and in this case only is there a demand for more oil from the engine supply. At all other times, 'Overspeed' and 'On Speed', the relief valve stays open relieving enough of the pressure to maintain 180-200 lbs./sq.in.

"Also shown is a cut-away section of the standard constant speed control mounted on the nose section of an engine with the propeller installed on the engine shaft. This gives a clear idea of the oil passage leading from the engine pressure supply to the booster pump and of the feeder line from the pilot valve to the propeller. In the feeder line the oil flows in both directions, to the propeller when decreasing pitch and from the propeller when increasing it.

"All Hamilton Standard controllables can be converted readily into constant speed propellers by the installation of a constant speed control on the engine and by conversion of the propeller to greater pitch range, if necessary. In some cases other minor parts have to be changed, but in every instance the conversion can be accomplished as a field modification.

"Operating characteristics of constant speed propellers require a departure from the conventional method of manual mixture adjustment. Any increase or decrease of power obtained by adjusting the carburetor fuel/air ratio is accompanied by a change of propeller pitch such that the r.p.m. is not affected. Tachometer indications, therefore, cannot be depended on as with fixed pitch propellers, and instead it is customary to use automatic mixture controls or fuel/air ratio indicators, such as exhaust gas analyzers and fuel flow meters.

"Provision is made so that the pilot can discontinue the governing action whenever desired and shift the propeller into full high pitch. This is important, however, only in case of engine failure on a multi-engine airplane, wherein the performance of the plane with one engine out can be materially improved by shifting the dead engine's propeller to full high pitch where its wind-milling drag is much less than in low pitch.

"The benefits derived from constant speed propellers are most apparent in the case of high performance airplanes, especially when equipped with supercharged engines. For high speed, especially when reduction gearing is employed, comparatively high pitch settings are required. On the other hand low pitch settings are required during take-off. Therefore, the range between low and high pitch is large for high performance planes and it becomes increasingly difficult for the two-position controllable propeller to provide satisfactory performance at all times.

"To illustrate the advantage provided by a constant speed propeller, the accompanying curves in Fig. III show the thrust horsepower available in level flight at cruising manifold pressure with a fixed pitch propeller, a two-position controllable propeller, and a constant speed propeller. The curves have been plotted from actual calculations based on a representative high performance airplane and engine.

"The lowest of the three curves shows the thrust horsepower available with a fixed pitch propeller set to give cruising engine r.p.m. at 17,100 feet altitude with full throttle in level flight. The intermediate curve shows the thrust horsepower available with a

fixed pitch propeller adjusted to give cruising r.p.m. at 10,000 feet altitude with cruising manifold pressure in level flight; and the third curve indicates the thrust horsepower available with a constant speed propeller installed on the same plane and engine. This shows that the maximum allowable cruising power can be utilized at all altitudes from sea level up to 17,100 feet altitude. With the constant speed propeller 18.6% more power is available at sea level than with the propeller set for 10,000 feet, i. e., a fixed pitch propeller or a two-position controllable propeller in high pitch. Likewise with the constant speed propeller, 34.8% more power is available at sea level than with the propeller set for 17,100 feet altitude, i. e., the high pitch setting of a two-position controllable propeller."

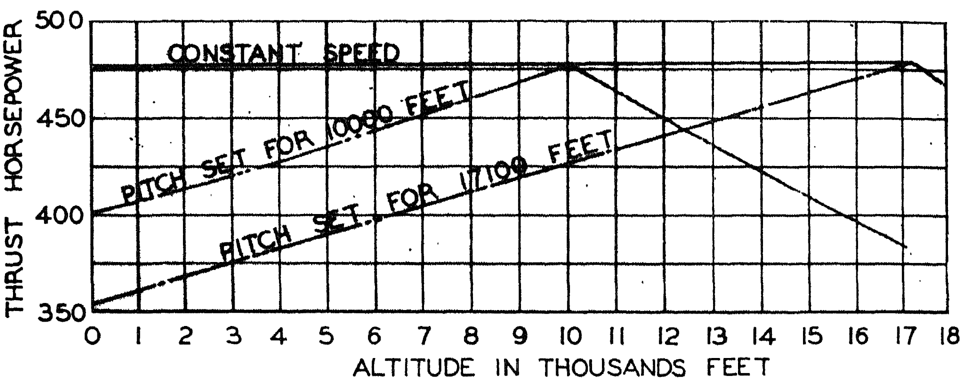


FIG. III

"Propeller Adjustments - Hamilton Standard propellers for constant speed operation are furnished with pitch ranges of either 10° or 20°. The 10° type is adequate for the average commercial plane, especially where high supercharging is not used. The 20° type is desirable for high performance planes with highly supercharged engines. This greater pitch range is necessary to permit full take-off r.p.m. at the blocks and also to prevent excessive r.p.m. when flying at high speed at high altitude.

"It is unnecessary and undesirable to employ a greater pitch range than that actually required. Consequently stops are provided in the pitch changing mechanism of the propeller so that the positive low and high pitch positions can be limited by adjustment. Normally these adjustments can be made without reindexing the propeller, but if reindexing is necessary the propeller must be disassembled and the procedure outlined in Hamilton Standard Service Bulletin #110A should be followed.

"If 20° propellers are used on land planes the limiting stops should be adjusted so that with the propeller in low pitch the engine will turn up at the blocks about 50 r.p.m. in excess of the full rated value. Thus if the engine is rated at 2400 r.p.m. for takeoff, the low pitch stops should be adjusted to allow the engine to turn about 2450 r.p.m. at the blocks at rated manifold pressure. This makes it possible for the pilot to set the constant speed control to 2400 r.p.m. while still at the blocks, and therefore permits him to run the engine at full takeoff power prior to starting to take off. As a precautionary measure it is advisable not to adjust the low pitch limit so low that it would be impossible to continue flight in case of the propeller being accidentally forced into positive low pitch. Actual flight tests should be made to determine the lowest low pitch at which the airplane can maintain level flight with the constant speed propeller in positive low pitch.

"If 20° propellers are used on seaplanes, the low pitch stops of the propeller should be adjusted so that the engine turns about 50 r.p.m. less than the rated maximum value at the start of the takeoff. If desired, stops located at the constant speed unit may be so adjusted so as to allow the engine to turn up 50 r.p.m. in excess of the rated maximum value and before flying the low pitch stops of the propeller should be reset so as to hold the engine about 50 r.p.m. below the rated maximum value.

"The adjustment of the high pitch limiting stop is normally that necessary to permit the constant speed to function in cruising descent from altitude or other normal conditions of power descent. This, however, requires the use of some form of automatic mixture control or suitable fuel/air ratio indicator. If mixture control accessories are not employed, the high pitch limiting stops should be adjusted to a lower pitch so that at cruising critical altitude the constant speed feature requires practically all of the high pitch for cruising power in level flight. This adjustment permits shifting, if necessary, to positive high pitch for manual mixture control.

"In many cases the performance of an airplane is not appreciably impaired by using propellers with only 10° pitch range although this may not be sufficient to permit full takeoff r.p.m. at the blocks as well as constant r.p.m. in a power descent. In such cases the performance may be entirely satisfactory by indexing the propeller so that the low pitch limit permits the engine to turn up to within 100 or 200 r.p.m. of the takeoff value at the blocks, while the high pitch limit is sufficiently high to prevent engine overspeeding under conditions of moderate power glide.

"In the case of 10° propellers the entire range can usually be employed, but where the full 10° is not needed the stops should be adjusted to limit the low pitch and high pitch as stated above for the 20° propellers.

"<u>Manual Adjustment of Constant Speed Controls</u> - In the installation of constant speed controls it is extremely important that the system provided for manual adjustment from the cockpit be properly constructed so as to permit the pilot to adjust the desired r.p.m. accurately and conveniently, so that when once adjusted it will not

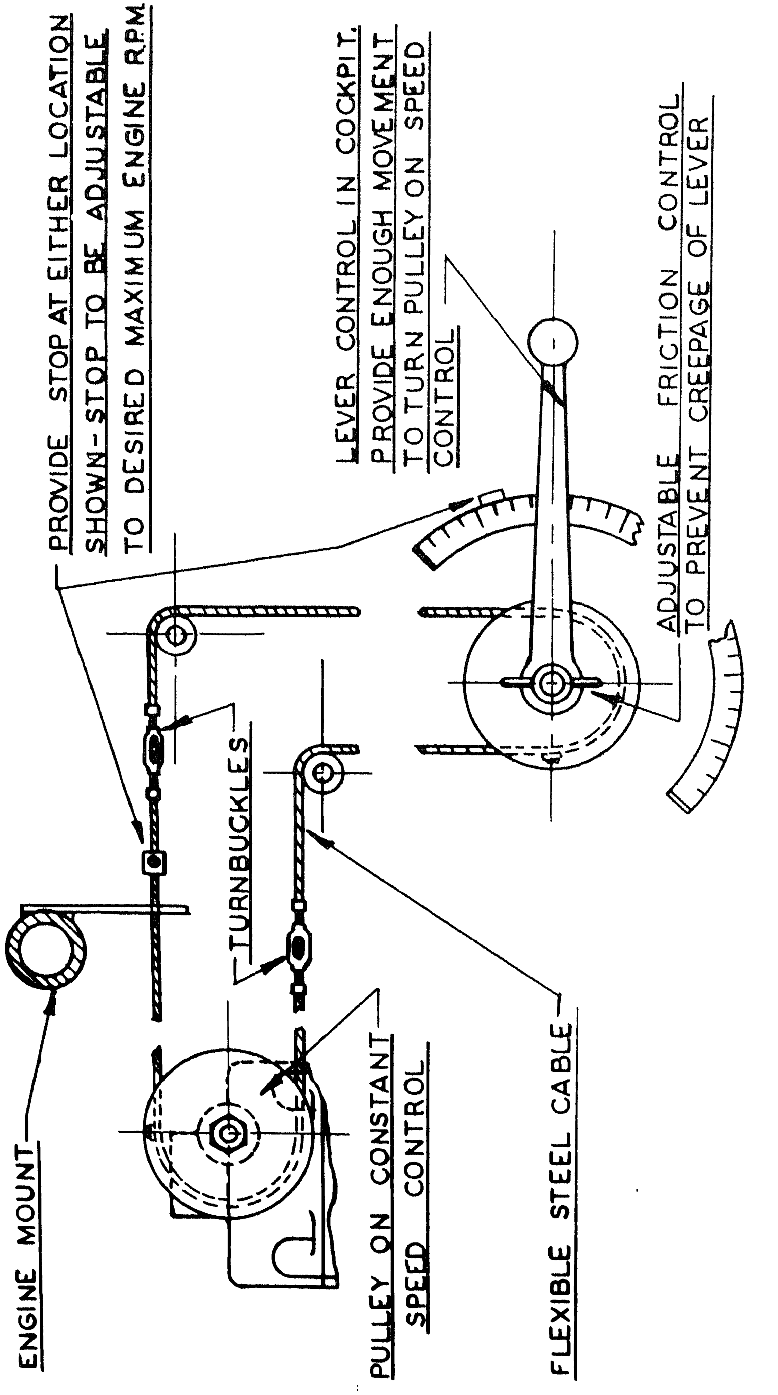

PROVIDE STOP AT EITHER LOCATION
SHOWN - STOP TO BE ADJUSTABLE
TO DESIRED MAXIMUM ENGINE R.P.M.
LEVER CONTROL IN COCKPIT.
PROVIDE ENOUGH MOVEMENT
TO TURN PULLEY ON SPEED
CONTROL
ADJUSTABLE FRICTION CONTROL
TO PREVENT CREEPAGE OF LEVER
TURNBUCKLES
ENGINE MOUNT
PULLEY ON CONSTANT
SPEED CONTROL
FLEXIBLE STEEL CABLE

FIG. IV

be subject to change. Consequently the system should be free from lost motion and not liable to 'creep.'

"Since the constant speed control governs the engine r.p.m. independent of throttle adjustment, it is essential that the method of manually adjusting the constant speed control be considered as important as the throttle installation. Fig. IV shows one of three representative types of systems which have been found satisfactory for manual adjustment of the constant speed controls. That illustrated makes use of cables and pulleys; the second utilizes push-pull rods and levers; and the third is a universal-joint torque tube system. Suitable levers or cranks can be employed in the cockpit as desired with any one of these systems. Other means of manual adjustment from the cockpit may be used and the selection of the type best suited to each installation is a matter which can best be determined by the airplane manufacturer or operator."

HAMILTON STANDARD HYDROMATIC QUICK-FEATHERING PROPELLER

A still further improvement in the controllable propeller is found in the hydromatic type, shown assembled in Fig. I and in

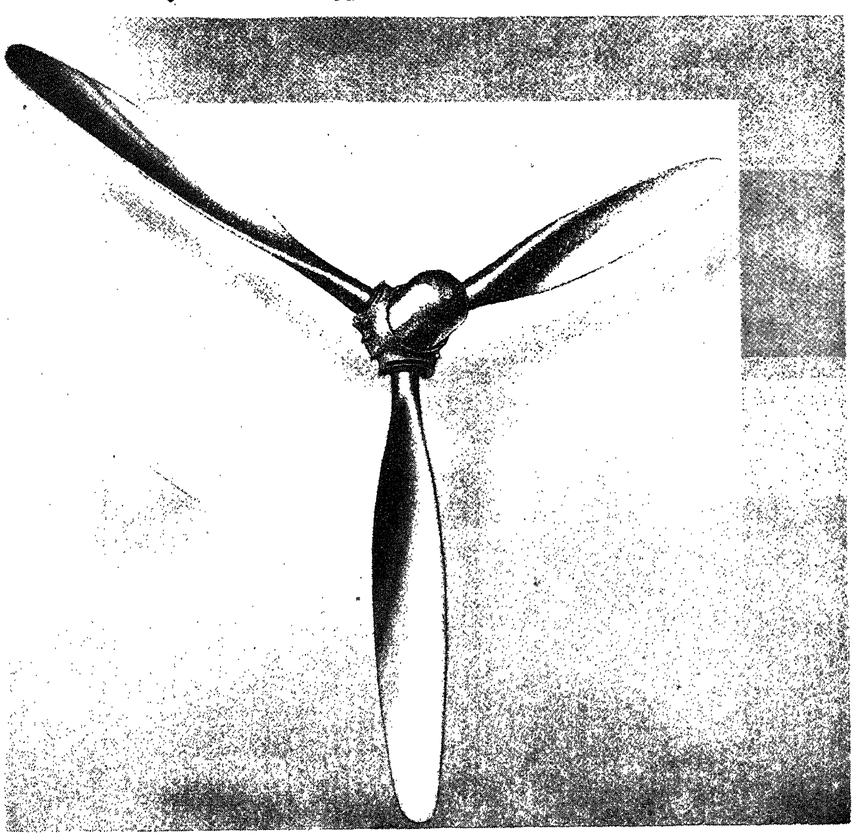


FIG. I

section in Fig. II. This propeller marks a notable advance in safety of airplane operation. The description and illustrations given here are supplied by the Hamilton Standard Company.

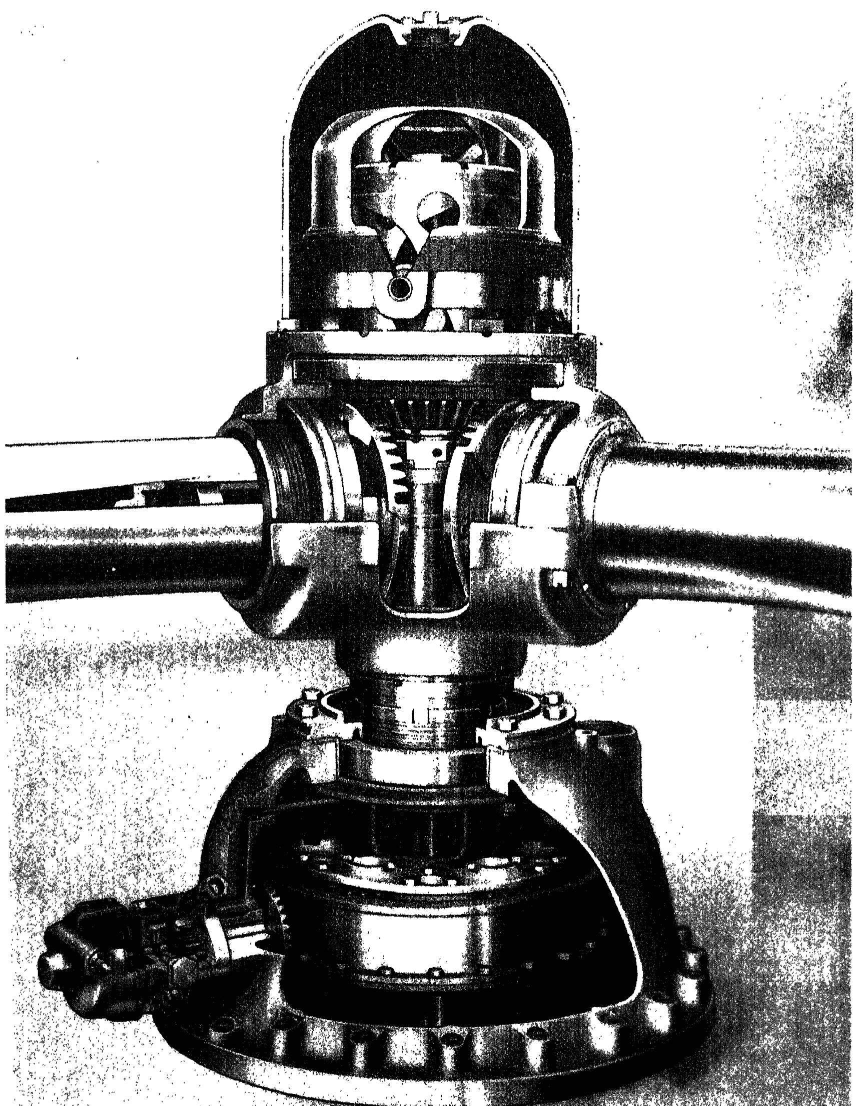


FIG. II

"The development of airplane performance has continued to the point where the range of pitch adjustment of existing propellers is barely sufficient to take care of the requirements. The speed range of new aircraft is steadily increasing, ceiling is increasing, and in military types there is a growing tendency for the use of power descents in certain maneuvers. All of these factors tend to require a greater range of pitch adjustment, and whereas the first controllables used only four or five degrees of pitch angle change, current types are using up to twenty degrees, and projected types will need still more.

"In addition to the requirements for additional pitch range, there has been a need in certain types of airplanes for stopping the rotation of engines which may have failed in such a way as to render their continued operation dangerous. In some cases this has been done by the use of friction brakes acting on the propeller shaft. The action of these brakes is comparatively slow, however, and resistance to forward motion of the airplane and the propeller stopped by the brakes is quite high. On the other hand, if the pitch angles of the propeller are rapidly increased to about 87 degrees at the three-quarter radius point, the rotation of the engines is stopped almost instantly and the resistance of the idle propeller is reduced to a minimum. The practice of adjusting the angles of a propeller to this position, where the chord of the blades is nearly parallel to the line of flight, is called 'feathering'. The difference in ceiling of a twin-engined airplane with one propeller feathered compared to the case of one propeller braked may be as much as 2,000 feet under certain conditions, so that the feathering procedure shows a material improvement in performance where one engine must be stopped. A number of airline operators have found the disposition of idle engines of great importance, especially in connection with long range operations, and the feathering feature enables them to solve a serious problem.

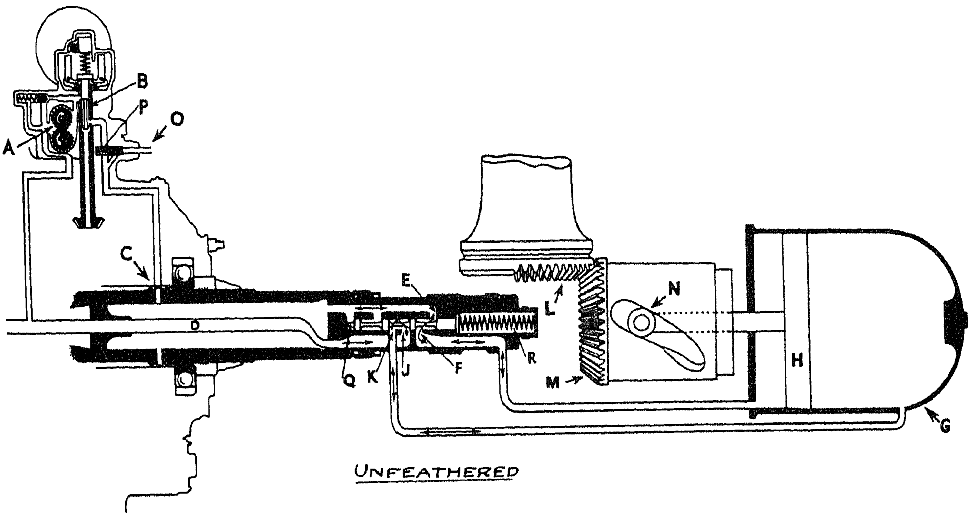
"Construction and Operation - Throughout the design, the seriousness and importance of the safety problem has been fully recognized. One of the most important advances in this connection has been the application of a method of measuring vibration stresses in the blades. This method has been under development in the Hamilton Standard laboratory for the past six years and is considered as offering a marked contribution to propeller safety.

"In construction, the Hydromatic propeller retains the rugged and successful hub and blade mounting structure of the older Hamilton Standard types. This has been further improved by moulding a collar of plastic material between the roller bearing race and the fillet of the blade retaining shoulder. This plastic material insures perfect seating of the mating parts, gives a better stress distribution, and protects the aluminum alloy blade from any chafing action, thus increasing its resistance to fatigue.

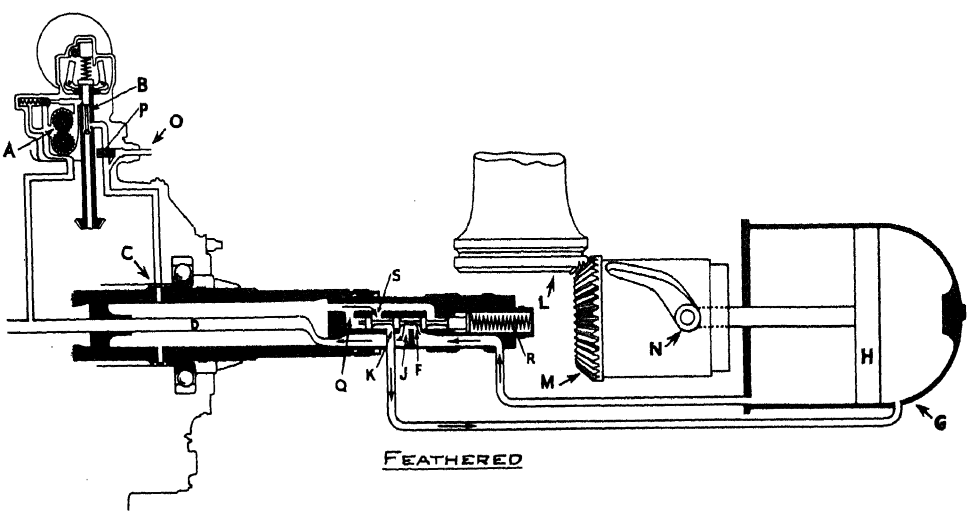
"The presence of the plastic layer also permits the use of an effective oil seal between the hub and blade. Such an oil seal would not be considered safe in direct contact with the aluminum alloy blade, as it might lead to stress concentration. With an effective

oil seal it is now possible to maintain a fairly high oil pressure on all the working parts inside the hub and wear of the parts is correspondingly reduced.

"The pitch control mechanism of the Hydromatic propeller is again of the simple, rugged hydraulic type, although differing somewhat in actual application from the earlier constant speed propellers. (See diagram in Fig. III.) One of the reasons for this is the



UNFEATHERED



FEATHERED

FIG. III

additional safety problem introduced as a result of the feathering procedure. Propellers in the feathered position will not carry out the normal propulsive function and it would obviously be dangerous if they could be feathered inadvertently or through improper functioning of the apparatus. Consequently, it is necessary to provide some means of restricting the pitch range during normal operation so that the blades cannot be feathered except by a deliberate action on the part of the pilot.

"This problem was solved by Hamilton Standard by taking advantage of the fact that the centrifugal force acting on the blades tends to cause them to go into low pitch. In the Hydromatic design, engine oil which has been boosted to higher pressure by the constant speed governor pump is used to overcome this centrifugal twisting moment when it is necessary to increase the pitch. This oil pressure acts on a large piston and the motion of the piston is transformed into rotary motion by means of a series of cam rollers acting on coaxial helical cams of opposite pitch slope. For the normal pitch range the cam follows a steep helical angle so that the piston enjoys a high mechanical advantage. When the pitch reaches the maximum operating value, the slope of the cam becomes flatter so that the mechanical advantage of the piston is insufficient to overcome the centrifugal twisting moments of the blades when the normal operating pressures are used. Thus, a maximum pitch limit is provided for the normal flight conditions. If a considerably increased oil pressure is supplied from some other source under the control of the pilot, the piston will overcome the blade twisting moment and the pitch will increase until the feathered setting is reached.

"The adjustment toward low pitch is also accomplished by oil pressure, supplementing and augmenting the centrifugal force on the blades. In this case, the oil is also engine oil but under normal pressure. This oil pressure is at all times acting on the opposite face of the propeller piston, and provides a 'resilient member' opposing any tendency for a change to higher pitch. Whenever the constant speed governor valve relieves the higher oil pressure on the other face of the piston, this resilient pressure, together with the centrifugal force on the blades, moves the blades toward low pitch.

"When it is desired to feather the blades, an auxiliary pressure supply system is put into operation. A typical example of such a system is shown in Fig. IV. The pump is mounted between the engine oil tank and the constant speed control, and sends oil under pressure through line O, shown in Fig. III, to the cut-out valve built into the base of the constant speed control. The auxiliary system shown in Fig. IV allows the pump to draw its oil from the engine oil tank; alternative installations have employed either a separate oil tank or used the hydraulic system of the airplane in place of engine oil and the special pump.

"The pump very rapidly builds up pressure in line O, disconnecting the governor from the propeller and at the same time opening this pump line to the propeller by compressing the spring P in the cut-off valve. This feathering oil pressure is transmitted to the rotating propeller shaft past the oil transfer rings C, see top view of Fig. III, through port E of the distributor valve assembly, out

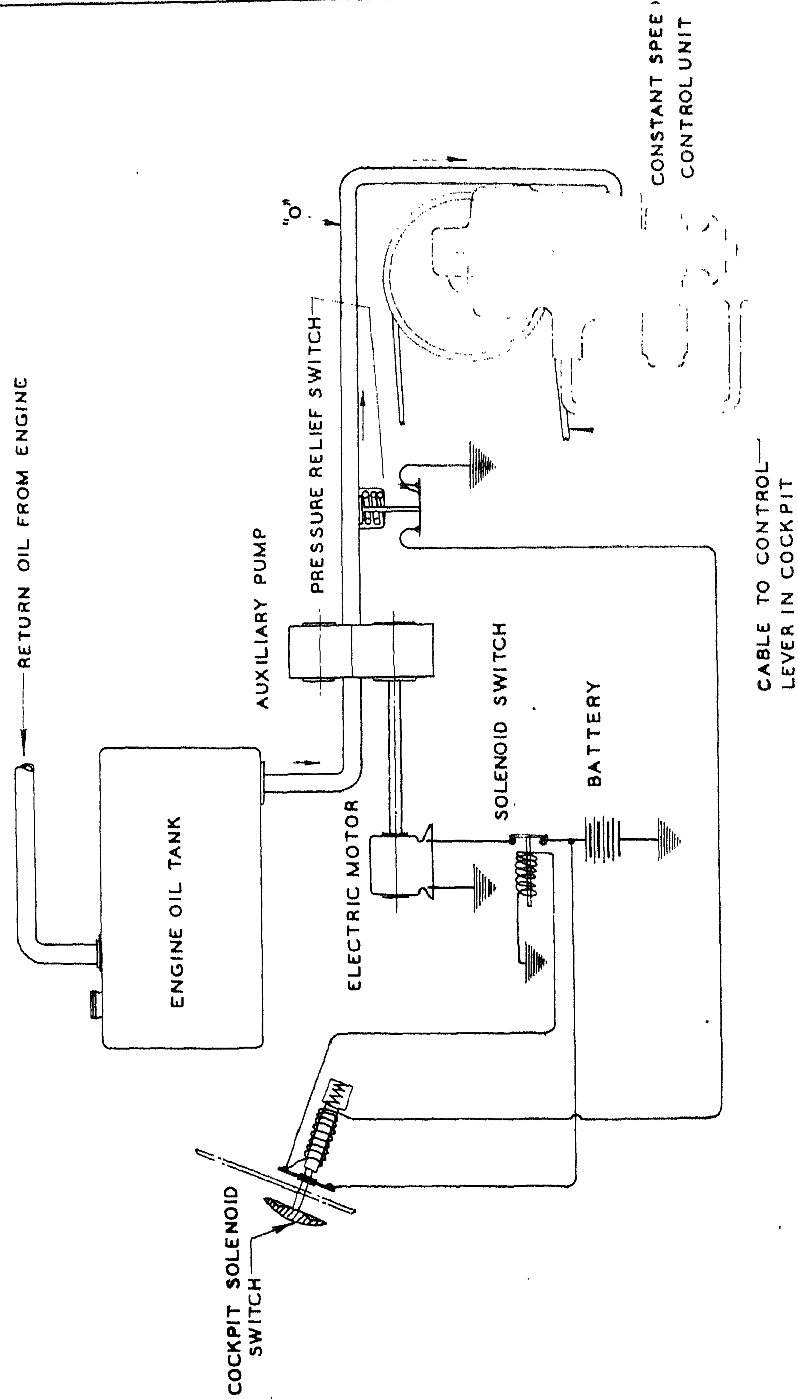

RETURN OIL FROM ENGINE
ENGINE OIL TANK
AUXILIARY PUMP
PRESSURE RELIEF SWITCH
"O"
CONSTANT SPEE
CONTROL UNIT
ELECTRIC MOTOR
SOLENOID SWITCH
BATTERY
CABLE TO CONTROL
LEVER IN COCKPIT
COCKPIT SOLENOID
SWITCH

FIG. IV

port F to the inboard side of the piston H. The piston moves out under this pressure, and forces the engine oil, on its outboard side in the dome G, through ports K and J, into the oil supply pipe D, and back into the engine lubricating system. As the piston moves out, the blades move to a higher pitch, and the motion is finally stopped by the rotating cam coming against an adjustable mechanical stop (not shown in the sketch) set for the fully feathered position of the particular blade design being used. With all motion stopped and the feathering pump still functioning, the feathering oil pressure builds up until it reaches 400 pounds per square inch, at which point a pressure cut-out switch opens the electrical circuit operating the pump by de-energizing the solenoid holding the cockpit solenoid switch in. With the blades feathered, engine rotation is stopped and consequently the blade centrifugal twisting moment and engine oil pressure have dropped to zero, and the blades remain in the feathered position. The entire feathering operation is accomplished in an average time of only 9 seconds.

"To unfeather the blades, the pump is again started and permitted to build up a pressure greater than 400 pounds per square inch simply by physically holding the cockpit solenoid switch closed (see Fig. IV). At approximately 500 to 600 pounds per square inch pressure, the force at Q at the base of the distributor valve in the propeller is great enough to force the distributor valve out, compressing spring R, and the valve moves toward the position shown in the bottom view of Fig. III, disconnecting the engine oil system from the dome. The oil from the pump starts to fill up the dome on the outboard side of the piston through ports S and K as the distributor valve moves out, and this oil starts pushing the piston in, unfeathering the blades. The oil on the inboard side of the piston is, of course, forced out through ports F and J into the engine oil system.

"The unfeathered propeller in an airplane moving through the air starts to windmill. When the engine reaches a reasonable r.p.m., the cockpit solenoid switch is released by the pilot. The propeller continues to windmill, cranking the engine, and it is thus possible to start the engine running again. The moment the feathering pump stops, the spring in the cut-out valve in the governor disconnects the feathering pump line from the propeller and places the governor back into the system, and the propeller runs again at the speed for which the governor is set by the pilot in the cockpit.

"The Hydromatic propeller during normal constant speed operation requires two simultaneous sources of oil supply, one being oil from the constant speed control booster pump and the other being oil under normal pressure from the engine oil system. Referring to Fig. III, oil from the constant speed control pump A is permitted to enter the hollow drive gear shaft B of the governor and thence to the propeller shaft when the engine is turning faster than the speed for which the governor is set by the pilot in the cockpit. Governor oil is thus metered at the top port of the drive shaft, and enters the rotating propeller shaft by means of the oil transfer rings C. It then follows the same path described above, for the oil during the feathering operation, to the inboard side of the piston.

"At the same time, oil from the engine lubricating system under normal engine oil pressure enters the propeller mechanism through the supply pipe D in the center of the propeller shaft, and reaches the outboard side of the piston through ports J and K.

"The governor oil pressure builds up until it exerts a force greater than the sum of the forces which oppose motion of the piston outward into the front of the dome. These forces are:

1. Engine oil pressure times the effective piston area.

2. The net blade twisting force consisting of the blade centrifugal twisting moment modified by the aerodynamic twisting moment.

3. Friction of the moving parts of the propeller mechanism.

"The net blade twisting force is transmitted from the blade gear segment L to the rotating cam M, and through the cam rollers N acting in the slots of the rotating cam, to the piston.

"The blade centrifugal twisting moment is a moment acting on the propeller blade around its longitudinal axis in the direction of a decrease of blade angle. It is the result of a force couple consisting of the resultants of components of centrifugal force acting on the mass of the propeller blade on either side of the blade's longitudinal axis. The aerodynamic twisting moment is usually opposite in direction to the blade centrifugal twisting moment, being caused by the position of the resultant center of pressure of the airfoil section of the blade in front of the center of rotation of the blade (the blade's longitudinal axis). In normal level flight this aerodynamic moment is relatively small in magnitude.

"When the governor oil pressure builds up to a value of force on the piston just greater than the sum of these three forces, the piston starts to move out toward the front of the dome, and engine oil in front of the piston is displaced back into the engine lubricating system. This outward movement of the rotating cam increases the pitch of the blades and the engine speed is thus slowed down. As the engine slows down to the speed for which the constant speed control is set, the pilot valve in the governor descends to the position shown in the top section view of the governor in Fig. III, thus shutting off the top port of the drive gear shaft and cutting off the supply of governor oil from the booster pump to the propeller. The oil under pressure from this pump, of course, then goes through the relief valve back to the engine, and the propeller runs on speed.

"Should the engine r.p.m. fall below the speed for which the governor is set, the pilot valve in the governor descends still further, opening the bottom of the drive gear shaft to drain. Engine oil in the dome at the outboard side of the piston is always, during normal propeller operation, under pressure from the action of the engine oil pump. This pressure acts as if a spring were placed

between the outer end of the piston and the front of the dome, the spring, however, having the unusual characteristic of exerting a constant force regardless of the amount of its compression. The blade centrifugal twisting moment, aided by this 'spring' force, moves the piston inward, overcoming friction and the back pressure existing in pushing governor oil back through the governor to drain. As the pitch of the blades thus decreases, the engine speed picks up and the pilot valve in the governor is raised, closing off the drain through the drive gear shaft just as the engine reaches the speed for which the governor is set.

"It should be noted that the relief valve in the governor is so interconnected with the engine oil system that the relief valve is held closed by the force of the relief valve spring plus the engine oil pressure force on the relief valve, whatever this may be. Thus, the effect is to provide a maximum pressure differential across the propeller piston equal to the relief valve spring setting, and the effects on the operation of the propeller of variations in engine oil pressure in any one engine or between engine types are eliminated."

THE LYCOMING CONTROLLABLE PROPELLER

This propeller, manufactured by the Aviation Manufacturing Corporation, through whose cooperation the accompanying description and illustrations are supplied, is mechanically operated by the power of the engine and the control may be mechanical or electrical, though in either case it is operated by the pilot. An indicator, which may be mounted on the instrument panel, shows the propeller blade angle at all times. The Lycoming Controllable Propeller is manufactured in various sizes suitable for aircraft engines with SAE and A-N standard propeller shaft and nose ends. The model designation adopted for these propellers combines: the prefix "P", the standard propeller shaft size number, the number of blades and the nominal blade shank size number. Thus, the Model No. P-321 Propeller is suitable for a Number 30 spline shaft and has two blades of Number 1 blade shank size.

The propeller illustrated in Fig. I is the Model P-220.

The hub of the propeller is a one-piece, chrome-molybdenum steel forging, heat treated

FIG. I

after machining. The blade assemblies are retained in the hub by nuts which are screwed into the ends of the blade barrel and properly locked. The gear mechanism is assembled into the hub.

The blades used in the Lycoming propeller are not aluminum alloy, as in the case of the Hamilton Standard type, but are made of chrome vanadium steel, are hollow and are chrome plated on the outside. The threads which carry the blade nuts are machined directly on the end of the blade shank or root.

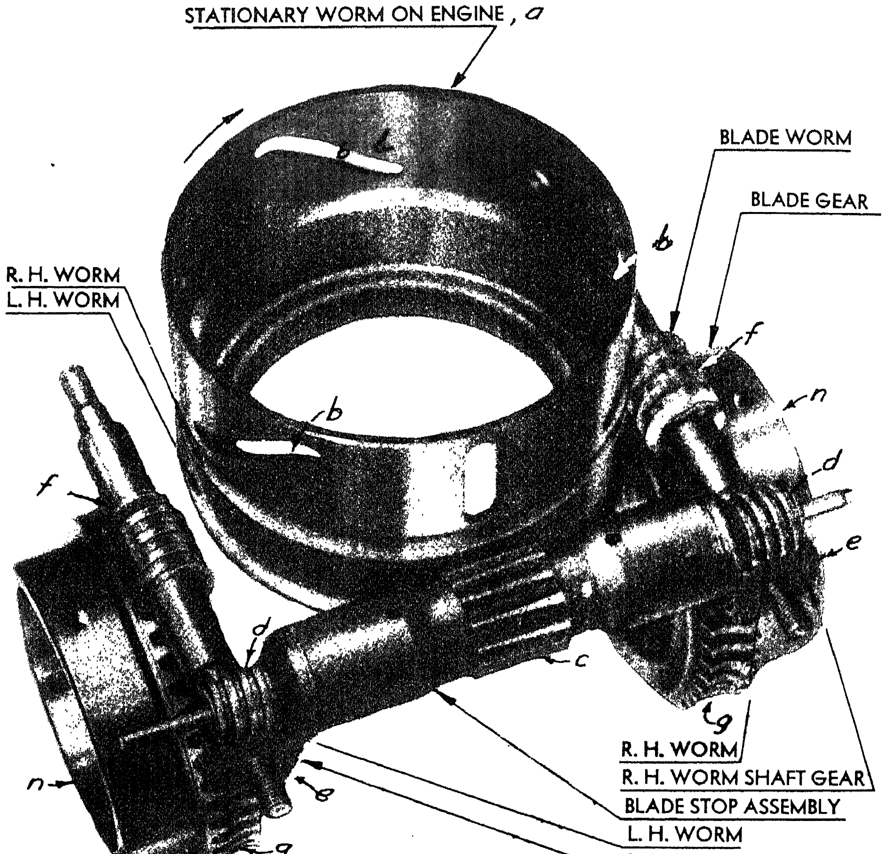


FIG. II

Fig. II shows the relationship of the important parts of the operating mechanism. It should be remembered that these parts are assembled into the hub which is roughly rectangular in shape, as may be seen in Fig. I. In Fig. II the hub is not shown, as too much of the mechanism would be concealed.

The nut on the end of the blade shank is provided with gear teeth, indicated by g, which engage the worms, f,f, on the blade worm shaft. The blade nuts, n,n, are screwed on the thread on their

respective blade shanks.

The blades in this propeller are tilted forward 1/2° , which lessens the bending stresses produced by the thrust load. On such models as are intended to be used with engines of over 500 h.p., each blade is also provided with a counter-balance to neutralize the twist caused by centrifugal force. The blades are fitted with ball-bearings to insure easy rotation of the blade when the pitch is being changed.

All of the parts shown in Fig. II rotate with the propeller except the stationary worm a. This cylinder or sleeve can be turned about its own axis through a few degrees and is operated by the cockpit control. In Fig. II the assembly is shown as viewed from the rear. In other words, the upper edge of the stationary worm is toward the rear of the engine. The sleeve is provided, near its front (or lower) end, with a right-hand worm thread and a left-hand worm thread, as indicated in the illustration. Either one of these worms may be caused to engage with the gear, c. As the propeller rotates, carrying with it the entire assembly except the sleeve, the teeth of the gear, c, if engaged with one of the other of the worms on the cylinder, will cause the shaft which carries the teeth (at c) to rotate on its own axis one tooth-space of the gear, c.

The sleeve is provided with diagonal slots, b,b,b, which fit over pins in a control adapter which is bolted to the crankcase. The sleeve will obviously move forward or backward on its pins if it is rotated. By this means, the sleeve can be set so that the right-hand worm, the left-hand worm, or neither, is in engagement with the gear c. Engaging the front, or left-hand worm thread, causes the blade angle or pitch of the blades to decrease, while engaging the rear worm thread increases the pitch.

When the gear, c, rotates, the shaft which carries it is, of course, caused to rotate. This shaft is fitted with small worms, d, d, at either end. These worms engage with gears, e, e, which naturally must rotate when the blade stop assembly rotates. As the gears, e, e, are turned, the worms, f, f, turn with them. These worms engage gear teeth, g, g, on the blade nuts. Since the blade nuts are rigidly secured to the blades, rotation of the worms, f, f, will cause the blades to rotate. Since a worm and gear of low pitch is irreversible, the blades are held in a fixed position except when one or the other of the worm threads on the sleeve, a, is engaged with the gear, c.

Fig. III shows the details of the blade stop assembly. This device is incorporated to limit the movement of the propeller blade. If there were no such stop, the pilot might set the control to change the pitch and having his attention distracted for some reason forget to throw the operating mechanism out of engagement. In this case, the pitch would continue to increase or decrease until no thrust were produced and the airplane would consequently be unable to remain in the air. In fact, the blade would keep on rotating until the pitch became negative. The propeller would then be exerting a negative thrust, or tending to push the ship backwards. The same

thing might occur if the control mechanism were damaged or failed to function in any way after it has been set for a change of pitch. The serious consequences of such an occurrence are obvious.

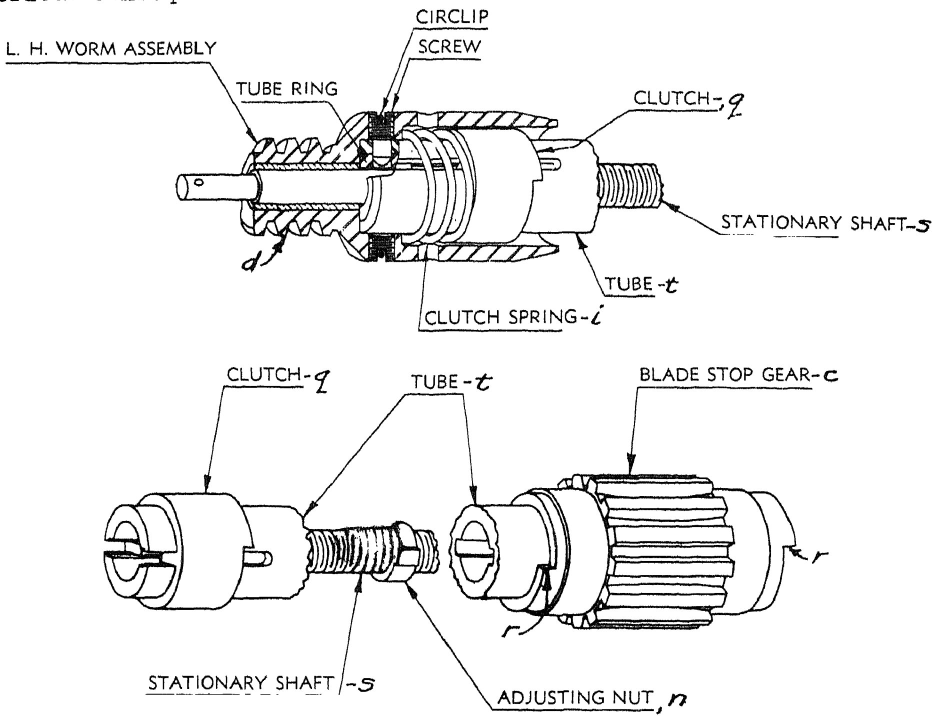


FIG. III

The operation of the blade stop mechanism is as follows: When the blade stop gear, c, is caused to turn by the worm thread previously explained, the tube, t, is rotated by means of the ratchet clutch, q, and the ratchet, r. The clutch, q, causes the tube to rotate by engaging with a slot in the tube. Inside of the tube is a stationary threaded shaft, s, which carries two adjusting nuts provided with projections which fit into slots or keyways on the inside of the tube, t. When the tube rotates, the nuts also must rotate. Since the shaft, s, is stationary, the nuts travel along with the shaft as they are being rotated. Eventually, one of the nuts pushes the clutch, q, along the slots in the outside of the tube until it disengages from the ratchet, r. The gear, c, continues to turn, but the clutch, the tube, and the worm, d, which operates the propeller blade, stop turning, and hence the pitch of the blade no longer is being changed.

Reversing the control brings the other worm thread, on the stationary sleeve previously described, into engagement with the gear, c. This causes the gear to rotate in a direction opposite to that just discussed, and through the ratchet clutch, r, likewise in the opposite direction. This brings the nuts back until the clutch on

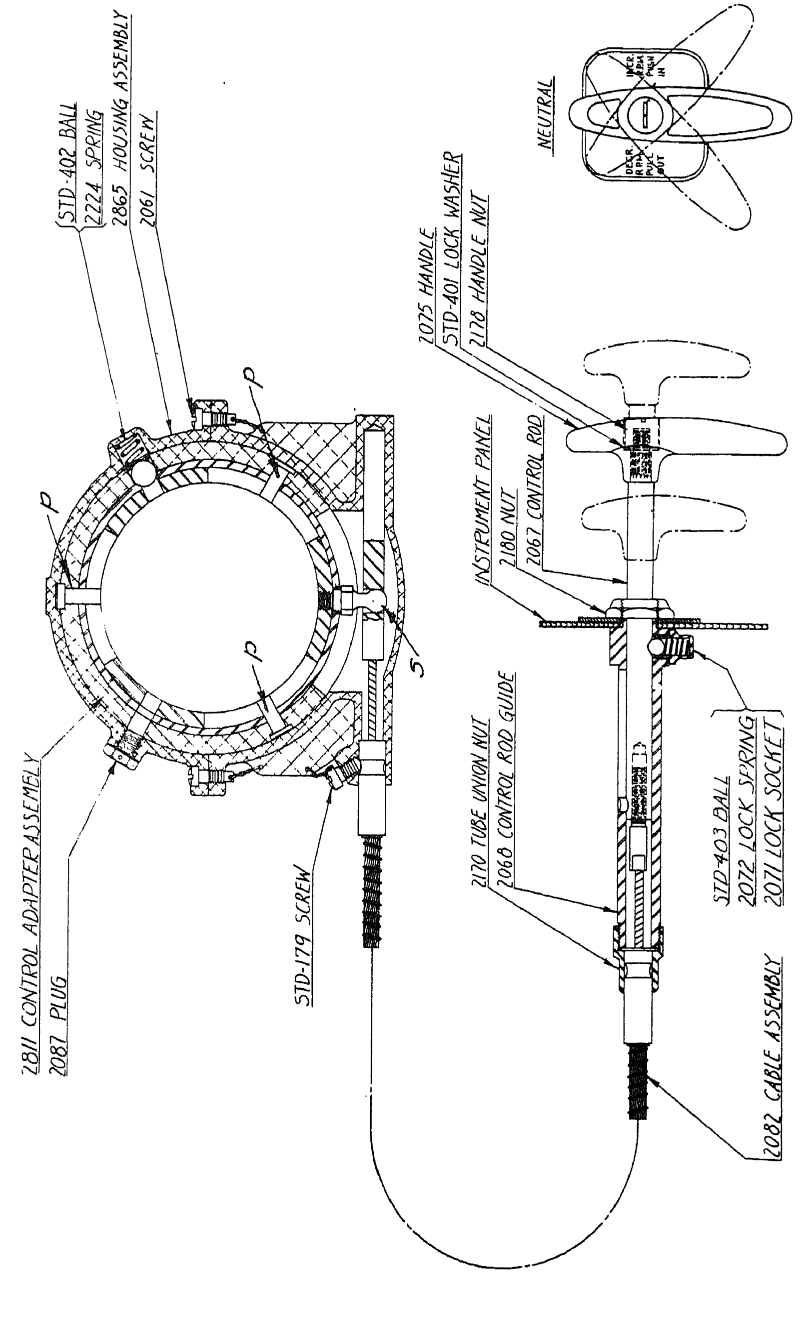

STD-402 BALL
2224 SPRING
2865 HOUSING ASSEMBLY
2061 SCREW
P
P
P
S
2811 CONTROL ADAPTER ASSEMELY
2087 PLUG
STD-179 SCREW
2075 HANDLE
STD-401 LOCK WASHER
2178 HANDLE NUT
INSTRUMENT PANEL
2180 NUT
2067 CONTROL ROD
2170 TUBE UNION NUT
2068 CONTROL ROD GUIDE
STD-403 BALL
2072 LOCK SPRING
2071 LOCK SOCKET
2082 CABLE ASSEMBLY
NEUTRAL
INCR. R.P.M. PUSH IN
DECR. R.P.M. PULL OUT

FIG. IV

the other end of the gear is disengaged in the same manner as the first. Meanwhile, the clutch spring, i, pushes the first clutch back into its original position, in engagement with the ratchet, r. By adjusting on the ground the distance between the adjustment nuts (only one of which is shown), the rotation of the blade stop mechanism may be limited to a definite number of revolutions before the clutches disengage in the manner described. Thus the upper and lower limits of the pitch may easily be set.

The manual control assembly, which sets the mechanisms just described into action, is illustrated in Fig. IV. This shows a cross-section of the control adapter, the handle in the cockpit and the connecting control cable. The pins which are fitted into the slot in the stationary worm (Fig. II, a) are indicated at p. The sleeve is twisted or rotated by means of the stud, s, which is engaged with the control cable. When the entire mechanism is disengaged, the handle is in a vertical and intermediate position. To increase the pitch, and consequently decrease the r.p.m., the handle is turned in a counter-clockwise direction and pulled out. To decrease the pitch and increase the r.p.m., the handle is turned in a clockwise direction and pushed in.

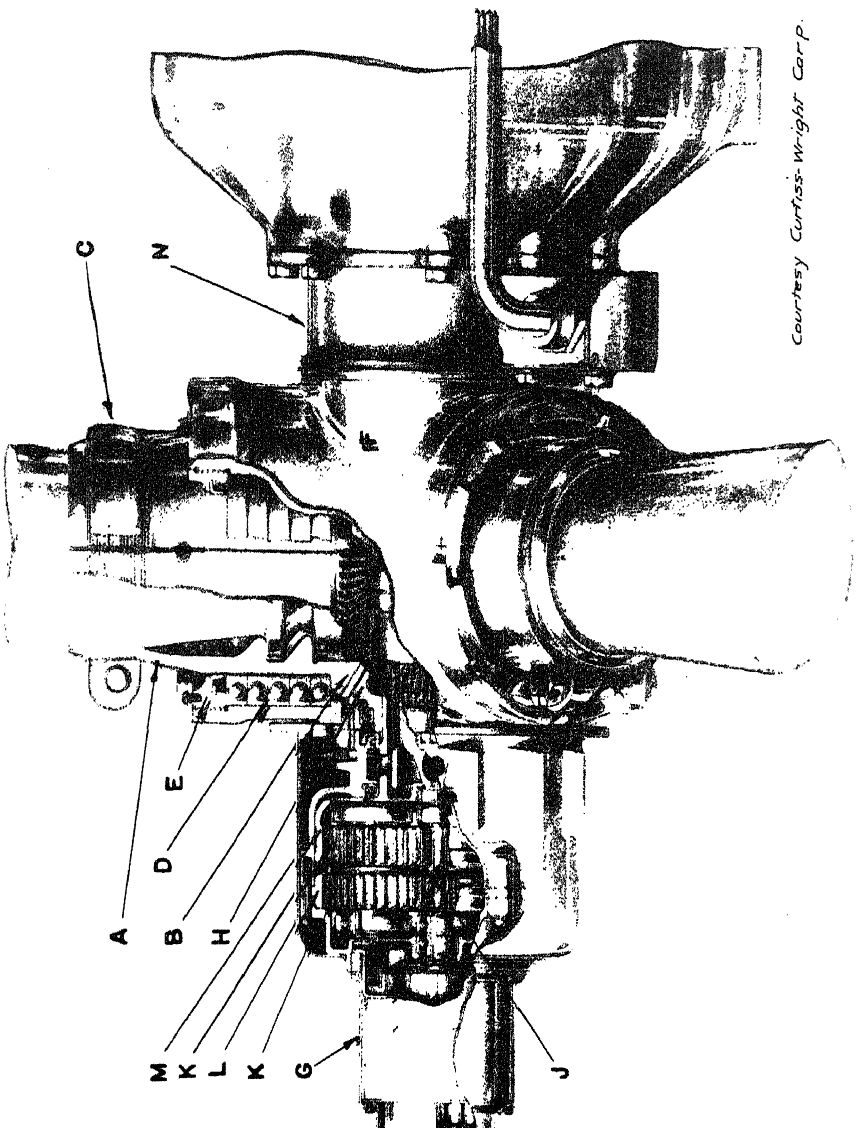
The mechanism may be actuated by means of a solenoid, energized by current from the ship's battery. In this case, the switches are usually connected to the throttle handle and are closed by rotating the handle slightly, turning it, as the manual control, counter-clockwise to increase the pitch and clockwise to decrease the pitch.

CURTISS CONTROLLABLE PITCH PROPELLER

The Curtiss Controllable Pitch Propeller is operated by an electric motor. The blades may be made of aluminum alloy, as in the case of the Hamilton Standard (in fact, the Hamilton Standard blades will fit a Curtiss propeller if the hub is designed for this type), or they may be of hollow steel construction, as in the case of the Lycoming. The hub may also be made to fit magnesium alloy or micarta blades. Regardless of the material used in the blades, the control mechanism and basic principles involved remain unchanged. In general it is recommended that the aluminum alloy blades be used on the smaller engines and the steel blades on those of relatively high h.p. The hub design used for aluminum alloy blades is shown in Fig. I. It will be noted that the blade shown is itentical with that used in the Hamilton Standard adjustable propeller. The root of the blade is enclosed in a steel sleeve, a, since aluminum alloy is too soft to function satisfactorily against the ball-bearings and also since some type of gearing must be provided.

The inner end of the sleeve, A, is machined to form the butt and gear, B, of the blade angle controlling mechanism, the combination sleeve and gear being clamped rigidly to the blade root by the clamping ring, c, at the outer end, and the ball-bearing, D, at the inner end. The clamping ring is similar to that used on the Hamilton Standard adjustable propeller.

The mechanism for producing changes of blade angle is driven by a D. C. electric motor, G. This motor is rated at .28 h.p. at



Courtesy Curtiss-Wright Corp.

FIG. I

1,800 r.p.m. The current is supplied from the standard 12-volt battery usually carried in the airplane and the consumption at full load is about 15 amperes. This power unit operates through a speed reduction device at a reduction ratio of 27,000 to 1.

The master bevel drive gear, H, is driven by this speed reducing mechanism. There is a further gear reduction due to the fact that the master gear is smaller than the bevel gear in the ratio of 3 to 4, thus making the total reduction 36,000 to 1.

The blades are rotated to increase or decrease the pitch by operating the motor in a forward or reverse direction. During the period in which no change is being made in the propeller pitch, the speed reducing mechanism acts as a lock, since, due to its extremely low gear ratio it is irreversible. Parts lettered J, K, L, and M, are various units in the system of reduction gear.

The electrical system used in operating the propeller is of the two-wire, or no ground, type. A brush adapted, N, attached to the engine front bearing-coverplate stud, holds the brush assembly in proper relation to slip rings mounted on the rear of the propeller. It should be noted that this brush adapter may be attached to any standard engine and that accordingly the Curtiss controllable propeller may be used on any engine without change of the engine oil system or any other internal parts.

In order to prevent changing the pitch past the danger point, and also to eliminate any creeping of the blades due to vibration, the electric motor shaft is provided with a spring-loaded brake which is always engaged when the fields of the motor are energized for changing pitch. The brake is automatically released, while the pitch is being changed, by means of an electro magnet connected in series with the armature of the motor. The slow end of the speed reducer is equipped with a set of electric cut-out switches which operate when the pitch has reached a predetermined limit. In addition to these switches, an adjustable mechanical stop is supplied which may be set to end the decrease of pitch about 1° below the point where the cut-out switch operates. This stop is simply an added precaution to make sure that the propeller blades are never set to a pitch which is too low for safe flying.

Current is transmitted to the motor by brushes in contact with collector or slip rings mounted on the rear face of the hub. There are four of these rings, made of brass and well insulated and protected from dampness or spray. Pitch is changed by holding the manual switch until the desired angle is obtained. This angle is determined by the manifold pressure and the r.p.m., and is indicated by an instrument in the cockpit. The pitch stops changing as soon as the switch is released.

THE CURTISS AUTOMATIC CONSTANT SPEED AND FEATHERING PROPELLER

The mechanism of the propeller itself is the same in this type as in the ordinary controllable. The only difference in the two is the automatic operation of the controls which is explained in the following paragraph, quoted from the handbook supplied by the Propeller Division of the Curtiss Wright Corporation:

"The governor consists of a spindle and flyweight assembly which is driven at approximately engine speed through a flexible shaft and adapter from a suitable accessory drive on the engine. An adjustable coil spring counterbalances the flyweight forces and at the same time operates a three-position switch by means of an actuating rod. The three-position switch consists of a movable contact between two fixed contacts, all three having tungsten points. The movable contact is held against the 'increase r.p.m.' contact by a pre-load on its bronze spring arm thereby closing the 'increase r.p.m.' circuit. When the governor spindle speed is not enough to cause the flyweights to overcome the coil spring force, the actuating rod does not bear on the switch arm, allowing the movable contact to remain firmly in place against the 'increase r.p.m.' contact. As the spindle speed increases, the centrifugal force of the flyweights compresses the coil spring and at the same time, through the actuating rod, moves the movable contact switch arm away from the 'increase r.p.m.' fixed contact, breaking the 'increase r.p.m.' circuit. While the movable contact is not touching either of the fixed contacts, all circuits are open and the propeller remains at the pitch angle at which it is set at the moment of breaking contact. If the r.p.m. increases further, the increased flyweight force will move the movable contact arm against the 'decrease r.p.m.' fixed contact, closing the 'decrease r.p.m.' circuit to the pitch change motor. As the engine r.p.m. decreases, the movable contact arm moves away from the 'decrease r.p.m.' contact, breaking the 'decrease r.p.m.' circuit, causing the propeller pitch to again remain fixed until another variation in engine speed occurs."

INSTALLATION OF PROPELLERS

Installation of Hub in Wooden Propeller- Wooden propellers must be fitted with a steel hub, usually supplied with the engine. This hub is in two parts: a rear flange made with a cylindrical center portion which extends entirely through the propeller and which is machined on the inside to fit the engine crankshaft; and a front flange, which is simply a circular plate provided with a single large hole in the center which fits over the cylindrical portion of the rear part, and a number of small holes (usually eight) for the propeller bolts. In most propeller hubs, the rear flange is equipped with a dowel which fits into a hole in the propeller boss and definitely determines the position of the hub with respect to the blades. In case no dowel is provided, the hub is usually inserted to that the keyway in the hub is in line with one of the blades. In assembling the hub to the propeller, the cylindrical portion is pushed through the hole in the center of the propeller boss and the bolts driven through from the rear with a rawhide mallet. The front flange, or face plate, is then slipped over the bolts and the nuts screwed on. The nuts should be tightened gradually and evenly. If all the nuts on one side are tightened first, the propeller may be thrown out of track. First one nut should be tightened until it is just snug, and then the nut diametrically opposite should be tightened the same amount. The sequence which should be followed is illustrated in Fig. I. After all the nuts have been pulled snug, they should be tightened in the same sequence and locked with cotter pins. After the propeller has been in service for a while, the cotter pins should be removed and the nuts checked for tightness.

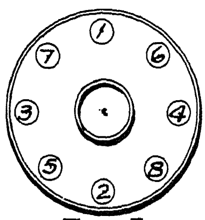


FIG. I

MOUNTING AND DISMOUNTING PROPELLERS

There are two types of crankshaft in common use: the tapered shaft, with a keyway, usually found on the smaller types of engines; and the spline shaft, which does not taper and which is almost universal on engines of more than 200 h.p.

Installation on Tapered Shafts- Hubs for tapered shafts are usually held on by a retaining nut which screws on the end of the shaft and a lock nut which screws into the hub against the retaining nut. This type is illustrated in Fig. I, which shows sectional views of the hub of a Curtiss one-piece metal propeller. Since this propeller is metal, the hub is not bolted in place as in the case of a wooden propeller, but the interior and the locking device is the same. Another type of retaining nut, occasionally used on a tapered shaft, is a single nut, threaded on the inside with a coarse thread to fit the end of the crankshaft and on the outside with a fine thread to fit the inside of the hub. Special care must be exercised when installing hubs provided with this type of retaining nut, for unless the threads are started properly, the nut may be pulled up tight inside of the hub while the entire assembly is still loose on the crankshaft. Retaining and lock nuts have two functions: first to hold the propeller tightly on the shaft; and second to act as a "puller" in removing the propeller.

If the propeller has never been installed on the particular engine, it may be necessary to lap the hub to the shaft. The fit may

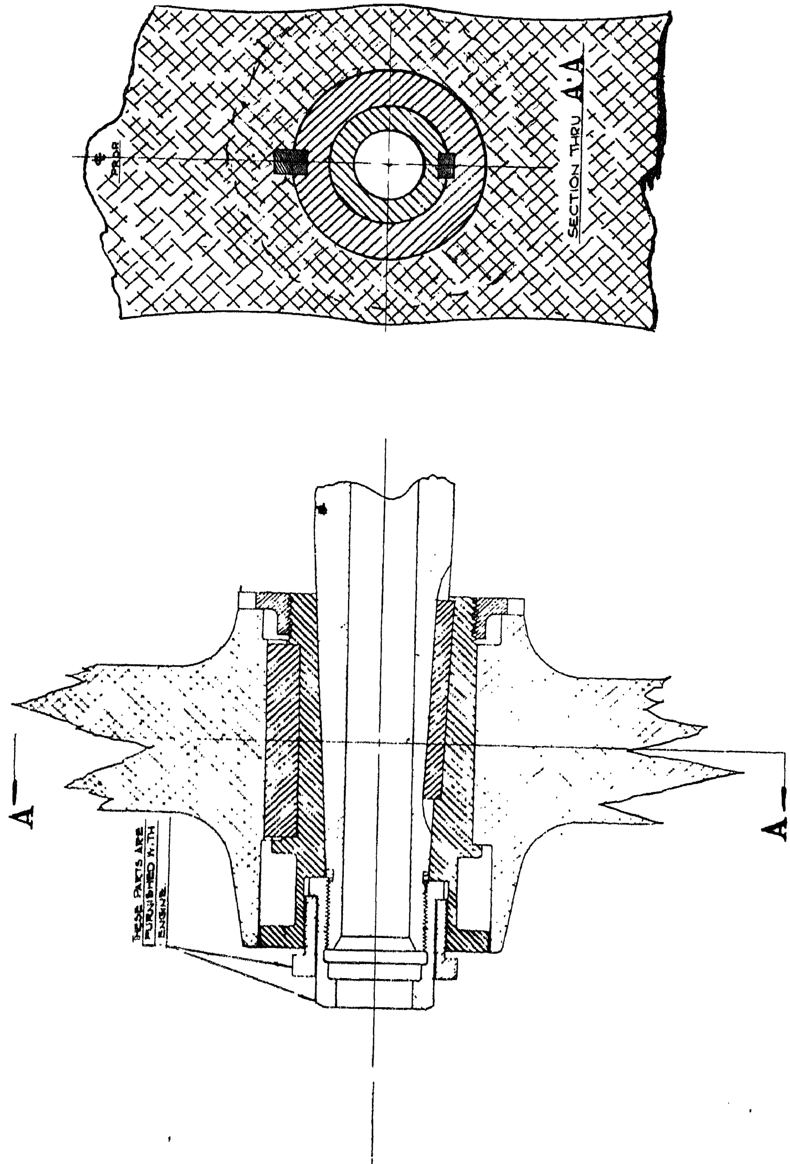

SECTION THRU A-A
PROP
A
A
THESE PARTS ARE FURNISHED WITH ENGINE.

FIG. I

be checked by removing the key from the keyway, coating the tapered shaft with a light coat of Prussian blue, pressing the hub in place and turning it about 45°. A thin film of blue should be transferred from the shaft to the large end of the inside of the hub and the small end should have little or none of the blue, as it is desirable to have a clearance of about .001" to .002" at the small end.

If the fit and clearance are not correct, the hub may be lapped to the shaft by using fine lapping compound, or fine valve grinding compound. A thin, even coating of the compound is spread on the shaft, the propeller carefully slipped into place, and swung back and forth through an angle of about 45°. After moving it through this angle several times, it should be rotated about 90° and the operation repeated until it has been worked entirely around the shaft. The propeller should then be removed from the shaft and all grinding compound cleaned from the inside of the hub. A fresh layer of the compound is then spread on the small end of the shaft and the large end coated with oil, and the lapping operation repeated. This procedure will give the desired clearance at the small end.

Before the propeller is installed on the shaft, the shaft must be thoroughly wiped with a clean cloth and lubricated with castor oil, light engine oil, or a thin mixture of castor oil and white lead. If there are any burrs or rough spots on the shaft, the key, or the keyway, they should be removed with a fine file or oilstone. Unless the shaft is smooth and properly lubricated, the propeller may "seize" to the shaft so that its removal is impossible.

After it has been determined that the hub fits the shaft, and the shaft is properly lubricated, the propeller is lifted into position, making sure that the keyway lines up with the key, and slipped onto the shaft as far as it will go. The retaining nut is then screwed on the end of the shaft, forcing the hub tightly into place. The nut should be tightened with a wrench or bar about three feet long. The crankshaft is prevented from turning during this operation by having an assistant hold the propeller or by locating the wrench on the nut so that one blade of the propeller is against the chest while the arms encircle it and pull on the wrench. The lock nut is then screwed into the hub and pulled up tight, though there is no occasion to use as much force as in the case of the retaining nut. Care should be used in starting the lock nut, since the thread is fine and may easily be crossed. Ordinarily, both the lock nut and the retaining nut are provided with drilled holes for safetying. The lock nut must be tightened until one of the holes in it lines up with one of the holes in the retaining nut. The two nuts are then locked together with a snap ring of spring steel wire, provided with a prong which passes through the two holes. After the engine has been run for an hour or two, the tightness of the nuts should be checked.

Removing Propellers from Tapered Shaft - The customary procedure in removing hubs provided with the double nut arrangement just discussed, is to loosen the lock nut several turns, then, holding it with one wrench, to back off the retaining nut against the lock nut until the hub is pulled loose from the shaft. Both nuts are then removed and the propeller taken off by hand. If it is impossible to

loosen the hub in this manner, the lock nut may be used as a puller instead of the retaining nut. The threads on the lock nut have less pitch than those on the retaining nut and hence will produce greater power. In following this method, the lock nut is unscrewed several turns and the retaining nut backed off until it comes in contact with the lock nut. The retaining nut is then held with one wrench and the lock nut screwed in against the retaining nut until the hub is loosened. This procedure should be followed only to start the hub; after it is started, the retaining nut should be unscrewed to finish the job to the point where the propeller is loose enough to be removed by hand. In extreme cases it may be necessary to remove the front flange, take the propeller off the hub, and heat the hub with boiling water. This naturally expands it and aids in its loosening. If there is room between the hub and the cylinders, a wooden block may be struck with a heavy hammer while force is exerted to unscrew the nuts. Care must be taken not to bend the rear flange if this method is used.

A limited number of small engines use a propeller puller which is a separate unit, very much like a gear puller. It consists of a cylinder, closed at one end and threaded on the inside at the other. The threaded end screws on external threads on the propeller hub and the closed end is provided with a heavy capscrew which may be screwed in against the end of the crankshaft. Such engines use a single nut for a retaining nut, which is locked by means of a large cotter pin passing through the retaining nut and the crankshaft. In removing a propeller of this type, the retaining nut is first removed from the crankshaft, the puller screwed on the propeller hub, and the capscrew screwed in against the end of the crankshaft until the hub is broken loose from the crankshaft.

Installing Propellers on Spline Shafts - Before installing a propeller on a spline shaft, the splines should be examined for nicks or burrs. These should be removed with a fine file or oilstone and the shaft cleaned and oiled in the same manner as the tapered shaft. Fig.II shows a cross-section of a Curtiss one-piece propeller mounted on a spline shaft.

On these crankshafts, usually one of the splines is wider than the others. When setting the propeller on the shaft, care should be taken that the groove in the hub which matches this wide spline is in line with No. 1 blade of the propeller. Furthermore, the wide spline is also in line with the throw of the crankshaft. This is an invaluable aid in determining roughly the position of the crankshaft when checking valves or timing the engine.

A spline crankshaft is provided with a front and rear cone, shown at b and c, respectively, in Fig.II. These cones are not a part of the propeller, but are supplied with the engine, as is also the case with the snap ring, r, and the retaining nut, n. All of these parts should remain with the engine if a new propeller is to be installed.

When the propeller is to be mounted, the rear cone, b, is put on the shaft, if not already there. The front cone, c, the nut, n, and the ring, r, should be assembled to the propeller. This is

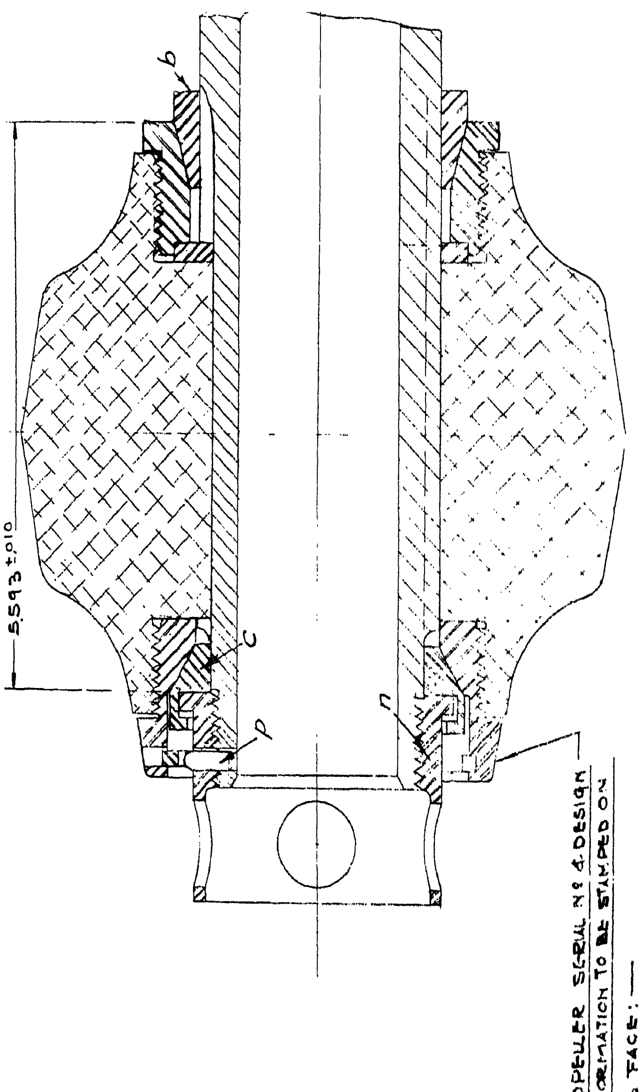

b
c
p
n
5.593 ±.010
PROPELLER SERIAL No & DESIGN
INFORMATION TO BE STAMPED ON
THIS FACE:—

FIG. II

accomplished by dropping the front cone and nut into the conical seat in the propeller boss and forcing the snap ring, r, into the groove provided in the propeller hub. The ring, r, is split, or cut, at one point so that its diameter may be decreased by squeezing the cut ends together. This enables it to be pushed into the hub until it reaches the groove, when it expands to its normal diameter and is held by its own springiness in the groove. The purpose of the ring will be explained later.

The propeller is pushed on the shaft by hand until the retaining nut engages the threads on the end of the crankshaft. The nut is then tightened by passing a steel bar through the holes in the sleeve, as illustrated in Fig.III, which shows the installation of a Hamilton Standard adjustable pitch propeller. To keep the crankshaft from turning during the tightening, it is well to put some sort of support under one of the blades, as shown in the illustration. A force of 625 ft. lbs. to 750 ft. lbs. should be applied by means of the bar. For example, if the bar is 4' long, a weight of 160 lbs. to 190 lbs. should be applied at its end with the bar at right-angles to the ground (not, of course, in the vertical position shown). While the weight is on the bar, the bar should be struck near the nut with a hammer weighing not more than 2-1/2 lbs. The hub should never be tightened by hammering on the end of the bar. It is extremely important that the hub be tight on the crankshaft, as any looseness will not only cause galling of the cones, but will allow the propeller to work on the shaft, causing a vibration which may not only damage the crankshaft, but other engine parts as well. The hub should be re-checked for tightness after the first flight and every time the engine has a periodic check.

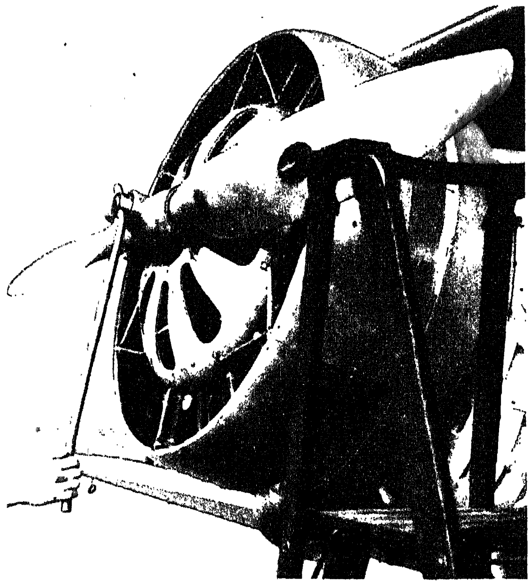
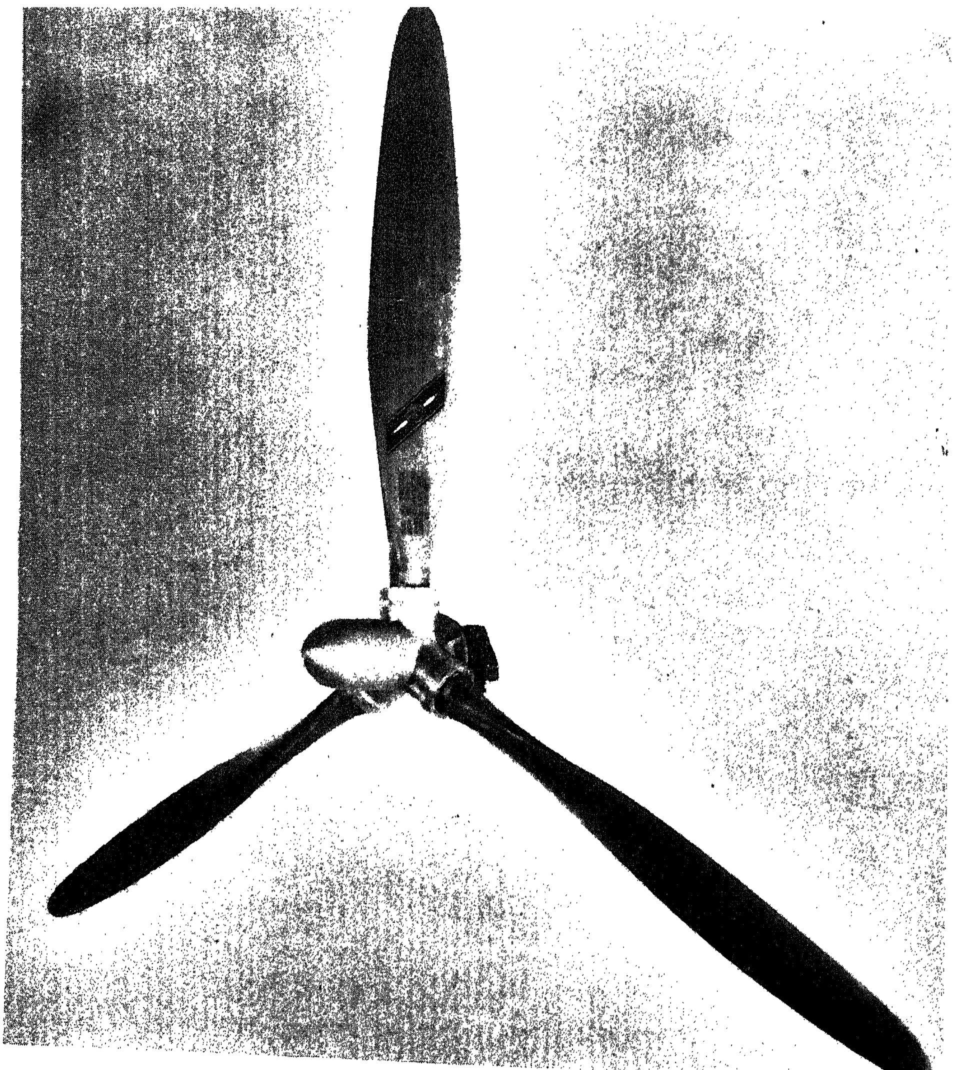


FIG. III

After the nut has been properly tightened, it should be locked by inserting a clevis pin, shown at p, in Fig.II, through holes provided in the end of the crankshaft and in the retaining nut. The head of the clevis pin should be toward the inside, or center, of the crankshaft, as when it is installed in this manner centrifugal force tends to hold it in place. The clevis pin is locked with a cotter pin.

Removal of Propeller from Spline Shaft - Propellers are removed

from spline shafts by taking out the clevis pin and unscrewing the retaining nut by means of a bar passed through the hole. This nut acts as a puller, as will be understood by a study of Fig.II. The front cone, c, is pulled back against the snap ring, r, by means of the nut. As the nut is further unscrewed, the shoulder on the cone, bearing against the nut, pulls the propeller off. It should be remembered that metal propellers are frequently quite heavy and that adequate assistance should be available when they are being installed or removed.



CURTISS ELECTRICAL PROPELLER

MAINTENANCE OF PROPELLERS

As stated before, any appreciable damage should be repaired by the properly equipped service station, and in any case, the propeller should be sent to such a station at intervals of approximately 200 hours of flying time. Aluminum alloy propellers, if not of the one-piece type, should be disassembled, thoroughly cleaned, and the hub inspected by the Magnaflux method for cracks. The blades of all aluminum alloy propellers (exclusive of the shanks of detachable type blades) should be lightly sanded to remove nicks and etched. Etching is accomplished by immersing the blade in a 10% to 20% solution of caustic soda. This is made by adding one or two pounds of commercial caustic soda to each gallon of water. When the surface is well blackened, it is rinsed with clean water and wiped off with a solution made of one part of commercial nitric acid to ten parts of water. The acid solution neutralizes any caustic action. It is desirable to heat the caustic soda solution to 160° - 180° F., which permits an immersion of the blade for only fifteen to thirty seconds to produce the desired etch. After the blade has been thoroughly examined for cracks it should be polished with a buffing wheel. All paint should be removed for etching. After the blades have been polished, it is desirable to give the rear surface of the blade a coat of black or maroon paint. If the blade is left shiny, it is likely to produce a glare which is extremely annoying to the pilot, particularly in a single-engine airplane; in fact, when landing with the sun directly behind the ship, the glare may be such that the pilot's vision is completely obscured. Obviously, this is an extremely dangerous condition.

If the blades are bent in an accident, they may be straightened by a properly equipped service station, provided the bend is not too severe and that the metal is not cracked. The Civil Aeronautics Authority specifies that the amount of the bend be determined with a protractor, according to the method shown in Fig. I. The requirements with respect to straightening are as follows: "Only bends not exceeding 20° at .15" blade thickness to 0° at 1.1" blade thickness may be cold straightened. Blades with bends in excess of this amount require heat treatment and shall be returned to the manufacturer or his authorized agent for repair."

Routine Service and Maintenance - Wooden propellers should be inspected at frequent intervals and invariably during periodic checks for such defects as cracks, bruises, scars, evidence of glue failure and separated laminations, sections broken, and defects in the finish. The tipping should be inspected for looseness or slipping, separation of soldered joints, loose screws or rivets, cracks, eroded sections and corrosion. During periodic power plant check their track should also be checked, as described in a later paragraph. There is little that can be done in the way of repairs on wooden propellers by a field mechanic. It is usually safe to revarnish the propeller, provided great care is exercised to keep the varnish even on both sides of the hub so as not to throw the propeller out of balance. Repairs to the tip should be made at a regular service station where equipment for balancing is available. The same applies to any correction of track.

Aluminum alloy propellers should be inspected daily for any damage which may have occurred during the previous flight. If they

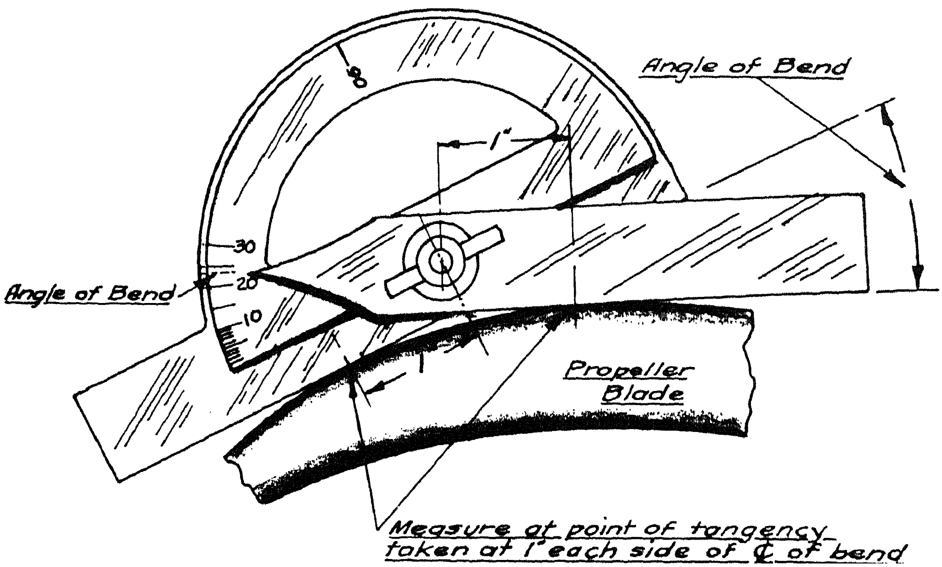


FIG. I

are used on a seaplane, they should be washed with soap and fresh water or thoroughly cleaned with kerosene after flight. A coating of engine oil should then be applied for protection. The tips of seaplane propellers should receive special attention, as they are likely to be continuously eaten away by a combination of erosion and corrosion. Any roughness should be removed immediately with fine emery cloth, preferably followed by crocus cloth. If the tips are not constantly smoothed in this manner, large holes will appear which will eventually necessitate removal of the tip and consequent reduction of the propeller diameter.

The following recommendations with respect to the care of minor damages are quoted from the Hamilton Standard Service Manual:

"Nicks and sharp dents on the leading edges, or gashes on the blade faces are particularly dangerous as they greatly reduce the fatigue strength at that particular point. A failure may result unless they are removed promptly. (All mars on the surfaces of the blades are 'stress raisers' and cause a stress concentration which may raise the stress beyond the endurance limit resulting in a fatigue failure.)

"Sharp dents and nicks or gashes may be removed locally without the necessity for reworking the entire blade surface. (See Fig. II.)

A curved 'riffle' file is recommended for use in removing the sharp base of the nick. Fine emery cloth or crocus should be used for polishing. Care should be taken in removing nicks from the blade face to insure that the thickness is not reduced more than is necessary.

SKETCH OF TYPICAL NICKS & METHOD OF REMOVAL

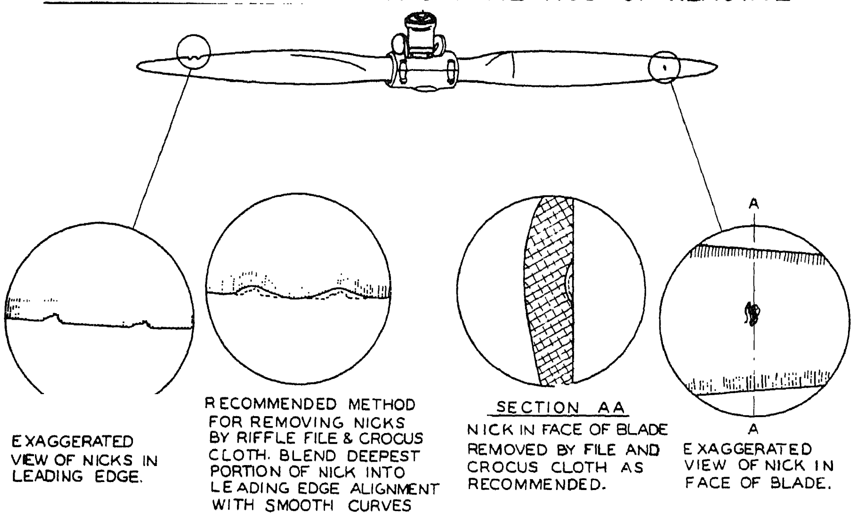


FIG. II

"It is recommended, as an added safety precaution, that the surface, after removal of a nick, be etched, examined with a magnifying glass, (to insure that the nick is entirely removed and that a crack has not started) and then polished locally. Propellers having very severe nicks or gashes should be sent to an authorized service station or the factory for repair."

The maintenance of hollow steel blades varies slightly in some respects from that of the aluminum alloy type, particularly with respect to the treatment of minor damages. The blades may be cleaned, as in the case of other metal propellers, with warm water and soap, gasoline (not ethyl), or kerosene. Steel wool, steel brushes, or any material that will scratch the surface should not be used, since the blades are plated and will rust if the plating is scratched through. After cleaning, the surfaces should be rinsed with fresh water and dried. A thin coat of clean engine oil should then be applied to all surfaces of the propeller. This is particularly important in the case of seaplanes.

The raised edges of any scars, cuts or scratches should be smoothed off with an oilstone. No more metal should be removed than is absolutely necessary and no tools other than the oilstone should be used. Small shallow dents on the leading or trailing edge, or near the tip of the blades, are of no consequence and do not require repair. It will be noted that this is just the reverse of the proper procedure for aluminum alloy blades.

The hub of the Lycoming Controllable Propeller must be kept full of SECO lubricating grease at all times. This is a special grease and is supplied by the propeller manufacturers. The procedure outlined in the service manual of this propeller should be followed. The same applies with respect to the hub lubrication of other types. As previously pointed out the care of the internal mechanism of all controllable propellers is a matter for authorized service stations and not for the field or line mechanic.

Tracking Propeller - Minor accidents, such as bumping into the propeller in the hangar, striking a wave with one blade, attempting to move the ship by pulling on one propeller blade, and the like, may throw the propeller "out of track." This may cause vibration, and should be checked immediately. In any case, propeller track should be checked during the routine periodic inspection. The procedure is quite simple, when the propeller is mounted on the airplane. See Fig. III.

SAFETY PRECAUTION - Check position of switch to see that it is OFF.

1. Turn propeller until No. 1 blade is at its lowest point.

2. Set stand (which may be a box or any other article of suitable height) in front of blade.

3. Mount indicator (which may be a slender, pointed strip of wood or any other similar pointer) on stand, holding it in position with weight, the point of the indicator just touching the nearest part of the blade.

4. Rotate propeller carefully, so as not to move ship until No. 2 blade is in same position as No. 1 was, viewed from the front.

5. If No. 2 blade does not touch point of indicator, measure the distance from the point to the nearest part of the blade. If, however, No. 2 blade is nearer the stand than No. 1 was, move the indicator back until it just touches No. 2.

   Rotate again until No. 1 is down and measure the distance from point to blade. With the point set to touch the nearest blade, the distance to the other should be not more than 1/8". Otherwise the propeller must be removed and sent to the service station for re-alignment.
   Naturally, if the propeller has more than two blades, the same procedure must be followed with each.

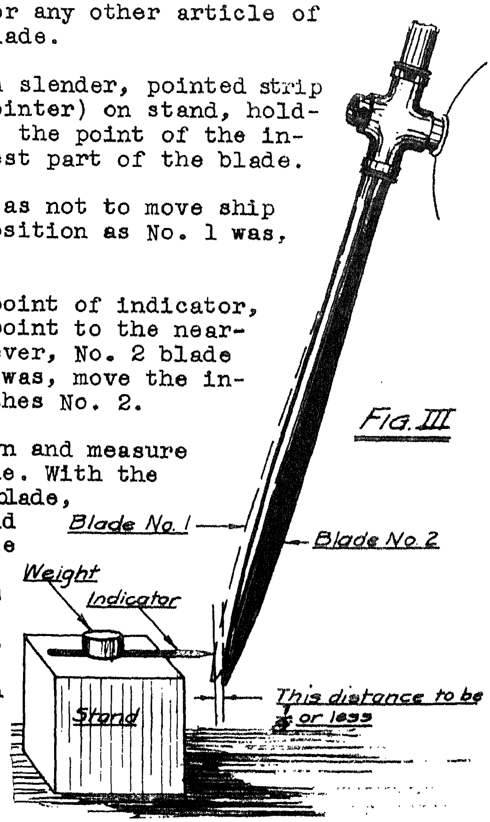


FIG. III

CHAPTER 14
PERIODIC CHECK

The importance of inspecting the various parts of the power plant installation cannot be over-emphasized. So many things can cause engine failure that only through constant and conscientious vigilance can the record of high dependability of aircraft engines be maintained. The items which are usually checked daily or before each flight have been listed previously; however, it is obvious that this list does not include all the items that should be inspected. There are many parts of the power plant that do not need to be checked daily, but they should be examined systematically and at regular intervals. In order to routinize the inspection of these parts and also to reduce the possibility of overlooking some item it is customary to group them together under what is known as the "periodic check."

Most engine manuals enumerate the items that are to be inspected and at what intervals these checks should be conducted. Naturally, these vary with different engines, making it impossible to give an exact procedure. However, bearing in mind that accidents are almost invariably caused by neglect, the following outline can be followed with a few modifications which may be necessary to adapt it to an individual installation.

Not only should the engine manual be referred to to see if there are any specific items to be inspected, but in addition the pilot's flight report should be consulted and any reports concerning the engine operation should be noted carefully. For example, if the pilot has mentioned that the fuel pressure gage seems to fluctuate more than is customary, the entire fuel system should be checked carefully in an effort to locate any possible trouble. In this connection it is well to refer to the chapter on "Trouble Shooting" for an itemized list of engine troubles and their causes.

GENERAL PROCEDURE

Conducting a periodic check is not a difficult task and by observing a few simple, common-sense rules, the job can be accomplished efficiently by any conscientious mechanic. The following items may not be universally applicable as they are stated, but with a few modifications will apply to all cases.

1. Make sure that the engine switch is OFF and that no one, working in or around the cockpit, is likely to touch the switch, booster or starter.

2. Provide yourself with a supply of clean wiping cloths. Do not use waste.

3. If it is necessary for you to climb on or around the engine installation, make certain of secure footing on some part that is designed to support your weight. Where possible, the use of suitable scaffolds and ladders is recommended.

4. Conduct the examination inside the hangar or in some loca-

tion that affords good light, yet is comparatively free from flying dust and grit.

5. Count or otherwise inventory your tools and wiping cloths and make sure they are all accounted for when the job is completed.

6. Make it a practice to check the items systematically. By doing this not only is a more thorough job insured, but the time required will be reduced.

7. Make it an iron-clad rule never to leave a job uncompleted. If, in the case of an emergency, a job must be left unfinished, a large warning tag should be tied to some adjacent point and a similar tag should be placed in the cockpit, preferably fastened to the ignition switch handle. Additional precautions should be taken to make sure that damage will not result to any part in case the airplane or propeller is moved. If the engine is open, that is, if a cylinder or accessory has been removed, suitable arrangement should be made to prevent the possibility of any foreign object entering.

8. Never be guilty of failing to inspect a part or a portion of a part that is not readily accessible simply because it is hard to reach. Often the parts that are the most difficult to inspect are those which need it most. It is true that installations in limited space present real problems to the inspector, but the seemingly impossible can often be accomplished with the aid of a flashlight and mirror. Incidentally, a mirror of the type used by dentists has been found to be invaluable in certain cases.

9. Remember that a part cannot be inspected unless it is clean.

10. Replace all safeties.

TWENTY-FIVE HOUR CHECK

In addition to the daily check, or inspection before flight, it is customary to inspect the power plant at regular intervals. These periodic inspections have become known as the twenty-five hour check, as they are conducted at the end of each twenty-five hours of engine running time. This inspection interval was originally determined by the length of time between oil changes and the time an engine could run safely between valve checks. Some engine manufacturers today recommend a fifty-hour period between oil changes and accompanying engine inspections. Other manufacturers enumerate some items which they feel should be inspected every ten hours. The frequency of the periodic check should be determined by consulting the engine handbook or manufacturer's recommendations.

As previously mentioned, it is impossible to give definite inspection rules which will apply to all engines, however, in general, the items to be inspected and the duties to be performed are very similar. Also the items in the following list are not necessarily arranged in the most efficient sequence. Assuming the engine has been cleaned previously, the usual procedure is to start with draining the oil and continue the inspection while the oil is draining.

Oil and Oil Lines - The oil should be drained from the oil

drain connection in the bottom of the oil tank into a clean container. The oil should be felt with the fingers to detect any grit or the presence of any metal particles. This may indicate the beginning of a serious engine trouble, such as burned out bearings, etc.

After the oil has completely drained out of the system the drain should be closed and safetied. Refill the oil tank with the correct amount and grade of lubricant. Care should be taken to see that any funnels, containers, etc., used when filling the oil tank, are clean and free from grit. If necessary they should be washed with gasoline and allowed to dry before using.

All oil lines should be wiped clean and inspected for cracks. Remember that any excess accumulation of oil may indicate a serious trouble. See that all oil pipe connections are tight. Inspect all hose connections to see that the hose is firm and in good condition and that the hose connections are in place and tight.

Carburetor

1. The carburetor strainer should be drained and cleaned and, if advisable, the carburetor fuel chamber should also be drained. (See chapter on carburetors.) If any dirt, water or rust is discovered the entire system should be investigated to determine the source.

2. Examine the carburetor and manifold anchorage to make sure that all brace tubes are in good condition.

3. Inspect for any evidence of air leaks, gas leaks, or blown gaskets. These may be indicated by a slight discoloration on adjacent parts, due to the dye used in fuels.

4. If the carburetor has an air cleaner it should be removed and cleaned with air pressure. If air pressure is not available the air cleaner should be washed in a bucket of clean gasoline and allowed to dry before replacing.

5. If air intake tubes are used, make sure that these tubes are cleaned inside, pointed in the right direction, and provided with a gasoline drain at their lowest points.

6. Examine all carburetor controls to make sure that they have full and easy action and are provided with correct stops. It is important to see that they are properly safetied and lubricated.

Plumbing - Plumbing is considered as including all lines, connections and accessories in the fuel, oil and cooling systems.

1. Inspect all tubing to make sure that there are no leaks or indication of cracks. The lines must not be too rigid, or engine vibration will cause them to crystallize. For this reason the plumbing lines are provided with vibration connections, or loops. If any copper line appears to have become hardened it should be removed and annealed.

2. Make sure that all lines are provided with necessary support and

are not in danger of chafing at any point, such as at the fire wall, etc.

3. Inspect all shut off cocks for leaks. See that they are securely mounted and test their control action.

4. Inspect the oil radiator installation to make sure it is properly aligned, securely anchored and that the controls work freely. Note: If there is any indication that the oil radiator is not functioning efficiently it should be removed and flushed with a mixture of light oil and kerosene. Remove the kerosene by flushing the radiator with clean oil before replacing.

5. Inspect the cooling liquid radiator for installation and alignment (core must be parallel to slipstream). Make sure that the core is clean. If the core is clogged it may be cleaned by compressed air. Never use a wire or stick to clean the core, as damage may result. Make sure that all connections are tight and vents are open. See that all shutter controls are in good condition and have proper control and lubrication.

6. Examine the cooling system pumps for leaks, especially around the packing glands.

7. Inspect all accessories for leaks.

Magnetos

1. Remove the magneto breaker point box cover and inspect the points for cleanliness and free action. Make sure that the breaker point pivot pin is free from rust.

2. Make sure that the points are square. Note: If less than 50% of the points' surfaces makes contact they should be removed and ground square. Check the clearance of the points and if necessary adjust them. See chapter on Ignition.

3. Check the synchronization of the magnetos.

4. Lubricate as specified in chapter on Ignition, replace cover and safety.

5. Check the magneto to see that it is securely mounted and that the couplings are tight and safetied.

6. Make sure that the segment blocks or distributor cap are safetied and that there is no oil on the magneto housing.

7. Make sure that the magneto ground wires are tight and in good condition. If possible, trace the entire length of the wires and see that the insulation is good and in no danger of chafing. Check the condition of the ignition switch wire leads.

8. Make sure that the booster wire is tight and presents no fire hazard.

9. Lubricate all spark control arms and make sure of free, full action. Be sure that both magnetos are fully advanced when the cockpit control is moved forward.

Ignition Wire Harness

1. If a radio shielded harness is used, make sure that the shielding is not broken and that the ground connections are tight.

2. Inspect, as far as possible, the ignition wires to see that they are not broken, chafed, burned or otherwise damaged. Make sure that they are in the clips provided and that the terminals are secure. If the spark plug terminals are secured to the plugs by safety wire make sure that the safety wire is not in a position to cause a short circuit.

3. Make sure that the wire manifolds are securely anchored and that the internal ignition wires are protected against any accumulation of water. If the manifold has been dented the insulation on the wires may have been damaged, which may eventually result in short circuits.

Spark Plugs

1. Remove the spark plugs, clean, reset and test, as described in chapter on Ignition.

Generators and Electric Starters

1. Inspect all wires to generators and starters to make sure that the terminals are tight and the insulation is good.

2. See that they are provided with proper lubrication as specified by the manufacturer's manual.

Batteries

1. Check all dry cells with an ammeter.

2. Check the level of the electrolyte in all storage batteries. If low, add distilled water to bring the liquid to the correct level. More complete instructions are given in the chapter on Ignition.

3. Inspect all heavy duty cables to make sure that they are free from corrosion and that the terminals are tight. If corrosion is noted clean the cable and grease with petrolatum (commercial vaseline). Loose terminals may arc in use, thereby constituting a fire hazard.

Propellers - Caution: Before inspecting propeller make sure ignition switch is OFF.

1. Inspect the propeller for any damage and especially for undue wear or pitting near the blade tips. Note: If the propeller is damaged in any way or if it is pitted to a degree which might

throw it off balance it should be removed and sent to a propeller repair station.

2. Move the propeller rapidly back and forth to see that there is no lost motion and that it is not loose on the crankshaft. Note: Do not confuse the play in the engine gears with lost motion of the propeller.

3. Inspect the propeller nut to see that it is tight and securely safetied.

4. Turn the propeller slowly and listen for any unusual noises in the engine. The compression of each cylinder should be noted also.

5. Check the propeller track.

6. Check the engine nose plate for cracks which may indicate a misaligned crankshaft. This is especially important if the propeller does not track perfectly.

7. If any undue vibration was noted on the last flight that cannot be attributed to the engine or the airplane, the propeller should be removed and its balance and blade setting tested.

Valve Action

1. Check all valve tappet clearances, adjust if necessary, and re-safety. Note: The engine manual should be consulted before this is done, as some manufacturers recommend that these clearances be adjusted at lesser or greater intervals of time.

2. Inspect the valve stem followers to see that they are not stuck. Rocker arm rollers must move freely and must have no flat spots. Lubricate the rocker arm assembly as specified in the engine manual.

3. Inspect the valve springs for rusty spots or broken springs. Make sure that the retaining washers are in place.

4. Lubricate the valve stems with some non-corrosive penetrating oil. If possible, make sure that the safeties and keepers are in place.

5. Check the rocker arms for side play.

6. If the rocker boxes are not an integral part of the cylinder, they should be checked for cracks and misalignment.

7. If the pushrods are to be removed check the rod ends for looseness, wear, cracks, etc. See that the pushrod is not bent. Note: This may be done by rolling the rod on a surface plate or a large pane of glass. Lubricate with grease recommended by manufacturer.

8. Replace and secure the rocker box covers. If gaskets are used make sure that they are not broken or unduly compressed.

Engine Mount

1. Inspect each engine mount bolt to make sure that it is secure and safetied. Note: If there is a black, powdery substance around a bolt the indication is that the bolt is, or has been, loose. If such is the case, the crankshaft near the loose bolt should be carefully cleaned and inspected minutely for cracks before tightening the bolt.

Induction Manifolds or Pipes

1. Inspect all intake manifolds and induction pipes to see that they are secure and have no air leaks such as may be caused by cracks, loose wire clips, blown or loose gaskets, etc.

Exhaust Systems

1. Inspect all exhaust manifolds and pipes to see that they are firmly anchored, safetied and without cracks. If the paint or metallizing is damaged, inspect for rust. If any flexible tubing is used make sure that it is in good condition and in no danger of burning, cracking, or rusting through. It is better to replace flexible tubing than to depend upon it too long.

2. Make sure that the exhaust outlet has not shifted so as to present a fire hazard by directing the exhaust toward any fabric, fuel lines, structural parts, etc.

Miscellaneous

1. Check all air baffle plates for correct position and anchorage.

2. Inspect all cylinders for burned paint which may indicate that the cylinder is running too hot. If any of this is found, make sure that the cylinder is receiving its share of cooling. If the cooling system is functioning properly the trouble is probably in the cylinder. Note: See Trouble Shooting.

3. Test the air shutter controls for free and full action, and lubricate.

4. Inspect all external accessories to see that they are secure and that all visible connections are good.

5. Inspect all cowling to see that it has no cracks, loose bolts, or loose machine screws. Make sure that it cannot chafe or interfere with correct engine operation.

From reading through the items listed in this periodic check, it might seem that this would be a long, difficult job. However, many of the items can be inspected on sight. An experienced mechanic can conduct a periodic check methodically and quickly and even though an inexperienced person will require much more time, none of the items mentioned here should be overlooked.

100 HOUR CHECK

At the end of each 100 hours' running time the following items should be inspected in addition to those mentioned in the twenty-five hour check. Inspect all accessories which are mounted on the crankcase by means of flanges or pads to see that they are tight, properly safetied and are not leaking oil.

Remove the propeller and inspect the front and rear cones for galling. See that they are properly seated in the propeller hub.

Check the compression by removing one spark plug from all cylinders but one. In the case of a radial engine the front plugs are usually more accessible. The compression should be tested by rotating the crankshaft in the normal direction. Each cylinder should be checked in its turn with spark plugs out of all others. By doing this a comparison can be made as to the amount of compression in each cylinder. If possible, the compression should be tested with a regular compression testing gage. Note: The compression cannot be tested properly unless the engine has been warmed up immediately prior to the check. If the compression in any cylinder appears to be below normal and the valve clearances are correct, the trouble shooting chart should be consulted for possible causes.

All copper tubing lines should be removed and annealed - see Fuel Lines.

Some manufacturers recommend that the preceding check be held at the end of 50 hours' running of a new or newly overhauled engine and at 100 hour intervals thereafter.

CHAPTER 15

POWER PLANT INSTALLATION

The installation of the various items and units which pertain to the power plant, such as the fuel system, the starters, generators, instruments, and other accessories, has been discussed elsewhere. This chapter deals with the installation of the engine itself and of miscellaneous accessories which do not fall into any specific classifications large enough to require a full chapter.

ENGINE MOUNTS

In modern airplanes the engine mount is almost invariably made of steel tubing, even if the rest of the airplane is built of sheet duralumin. In the case of radial engines, the mount consists of a ring provided with fittings for the mounting bolts and attached to the rest of the structure by a truss of welded steel tubing. Some means of absorbing vibration is usually provided. On small and inexpensive ships this may consist of a piece of brake lining placed between the engine crankcase and the bracket through which the mounting bolt passes, or of a piece of rubber hose surrounding the mounting bolt. Most modern ships, particularly of the more expensive type, are equipped with some more satisfactory device for the reduction of both vibration and noise. Among the most popular of such devices are those made by the Lord Manufacturing Company.

In Fig. I is shown one type of the Lord vibration absorber. This type, as may be seen from the illustration, is used at the points where the engine mount is attached to the fuselage or wing structure. Three approved methods of attachment to the structure are shown in the lower portion of the illustration.

This type of vibration absorber also lends itself readily to an in-line installation. A mount for a line or V-engine naturally uses no ring such as that shown in Fig. I, but is provided instead with two horizontal tubes which carry the engine and which are supported by a truss similar to that illustrated.

Another and more popular type of Lord vibration absorber is shown in Fig. II. It will be noted from the sectional views that the rubber is in shear and that the absorbers are in a plane parallel to the plane of the cylinders and arranged with their axes tangent to a circle the center of which is the centerline of the crankshaft. This arrangement provides for the absorption of torque vibration as well as any other type of vibration, through shear in the rubber. The rubber is cemented securely to the sleeves passing through and around it respectively. Since, in a mount not provided with such a means of shock absorbing, the engine vibration and noise pass through the engine mount into the fuselage and cabin, the system illustrated does much to maintain quiet in the cabin, as well as eliminating fatigue stresses in the engine mount and structure. The flexibility of the mount shown in Fig. II is rather startling to one not familiar with it, as when the engine is starting or running irregularly the entire cowling and all parts of the engine rotate back and forth very noticeably. However, when the

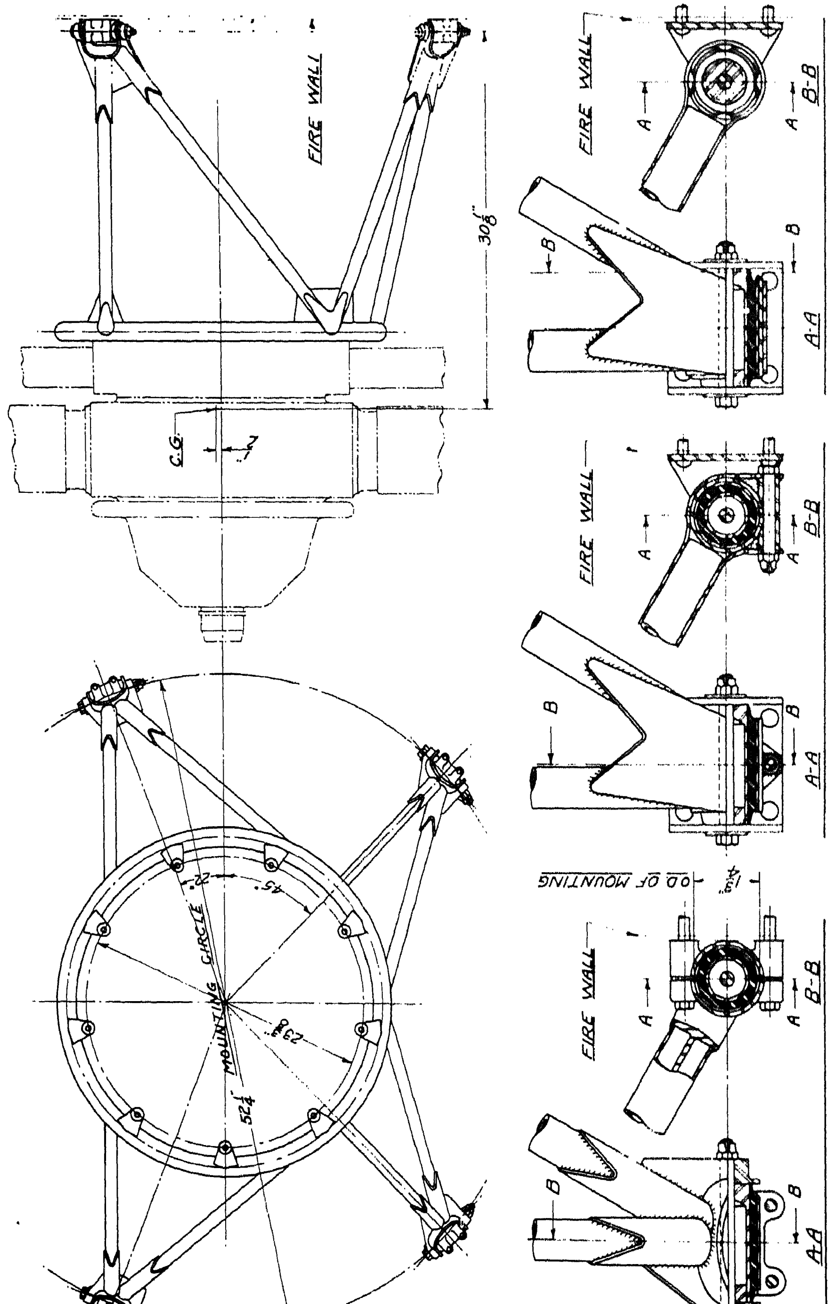

FIRE WALL
FIRE WALL
FIRE WALL
FIRE WALL
C.G.
A-A
B-B
A-A
B-B
A-A
B-B
MOUNTING CIRCLE
O.D. OF MOUNTING
45°

FIG. I

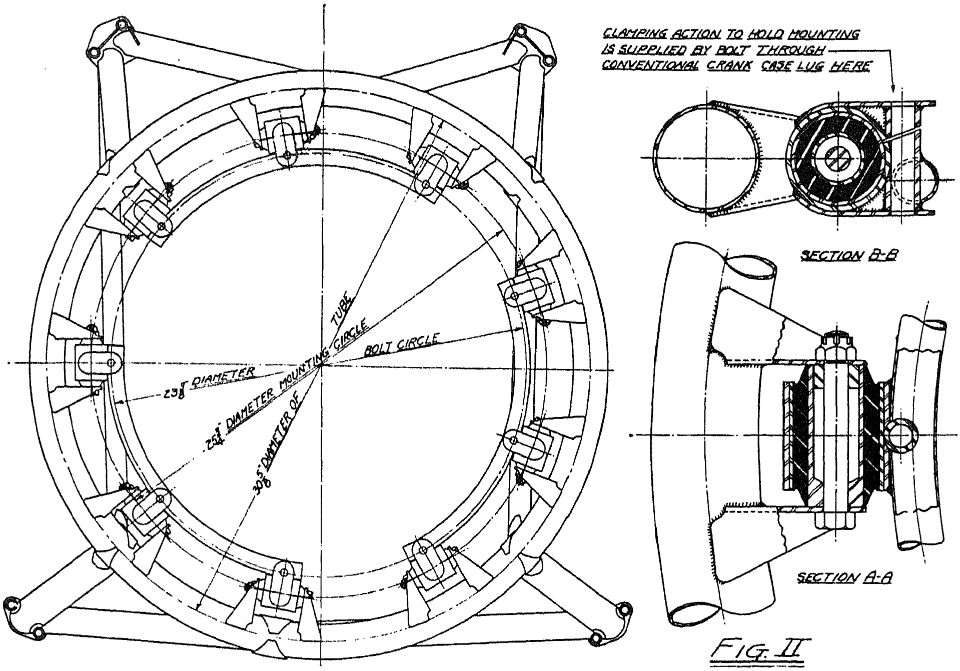


FIG. II

engine is running smoothly, little or no movement can be seen. A photograph of an engine installation using a mount of the type shown in Fig. II and carrying a Pratt & Whitney Wasp, Jr., may be seen in Fig. III. In the lower view, the oil tank and air heater are installed, but in the upper view these items are removed so that the remainder of the installation is not obscured.

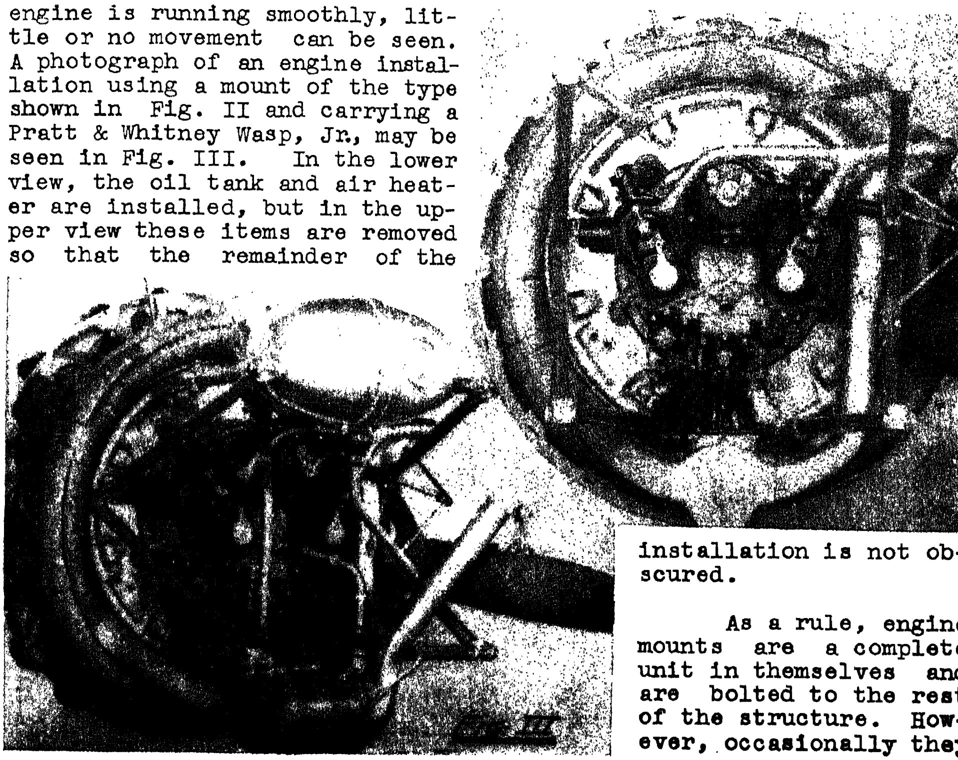


FIG. III

As a rule, engine mounts are a complete unit in themselves and are bolted to the rest of the structure. However, occasionally they

are welded in place or else the truss is formed by extending the longeron; this latter arrangement being adaptable, of course, only to fuselages built of steel tubing. In any case, they should be frequently inspected, particularly at the joints, for cracks, either in the weld or in the tubing itself. Due to the vibration and the abuse to which the mount is subjected, it is much more likely to crack than other portions of the airplane and furthermore any cracks cause a serious hazard. If a crack is discovered at any time, the ship should naturally be grounded until repairs are made. These repairs usually consist of welding a plate over the damaged area. It is, of course, necessary to remove the engine, or at least to support it by a hoist while welding is being done on the mount; otherwise, when the tubes are heated, the weight of the engine may distort them permanently.

INSTALLATION OF ENGINE

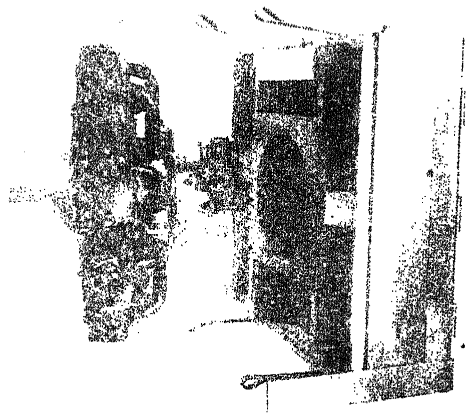
Throughout the entire process of installing the engine and making the various necessary connections (fuel lines, oil lines, instruments, controls, etc.) the utmost care should be used, both to make connections properly and to avoid damaging the more delicate parts of the engine. An aircraft engine is a rugged mechanism, capable of withstanding almost unlimited service provided the parts are not subjected to strains for which they were not designed. For example, the cooling fins are not likely to be damaged in normal operation but may easily be bent or broken if struck accidentally with a hammer. Likewise the intake pipe will last indefinitely if not abused but may be easily bent by a hoisting sling, or chafed through by improperly fitted cowling. No attempt should be made to handle an engine without adequate hoists and equipment since dropping it is likely to damage it beyond repair.

Removing Engine from Crate - Engines are usually shipped in crates so designed that the top and the four sides may be removed as a unit, leaving the engine fully exposed and supported on a framework built up on the bottom of the crate. The removal of several bolts, the location of which can ordinarily be readily determined by examination, will permit the top and sides to be lifted clear. If the engine has been shipped from the factory, it is usually covered with oilcloth. This should be removed and preserved for future use.

Most of the larger engines are provided with some means for attaching the hoist. In the Pratt & Whitney models, lifting eyes are screwed into the crankcase on each side of No. 1 cylinder. On Wright engines lifting plates are attached by removing the rocker arm hub bolt nuts from the exhaust rocker arm bolt of No. 2 cylinder and the intake rocker arm bolt of No. 9 cylinder, then replacing the nuts with the lifting plates fitted on the round portion of the nuts. Other makes of engines use various methods of attaching the lifting sling. The method should be determined from the engine instruction book before any lifting is done. In an emergency a strong rope may be passed around the barrels of cylinders No. 3 and No. 8 (in a nine cylinder radial), below the cooling fins, provided the rope may be led in such a manner that when the strain is put on it, it does not touch any fragile part of the engine. Another emergency method is to pass a rope sling around the crankshaft, up to the hook of the hoist and then around the rear of the crankcase, again taking care that

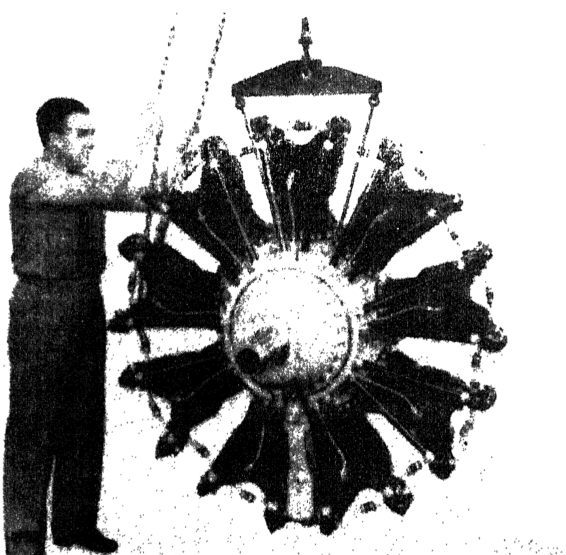
the rope does not bear against any part which might be damaged. This last method is not feasible when mounting the engine on a ring mount, since obviously the lifting rope will interfere with the ring. In the case of engines of 50 H.P. or less, it is sometimes possible to dispense with the hoist and have two mechanics lift the engine in its place. This procedure, however, is not recommended.

Having attached the sling properly, the slack should be taken up with the hoist and, in the case of a radial engine, the bottom of the crate turned on edge, as illustrated in Fig. I, meanwhile keeping the sling taut by operating the hoist. The sling should be provided with a spreader bar, as illustrated in Fig. II. If cables are used instead of the standard sling shown in the illustration, they may be held apart by a stout piece of wood, notched at each end. After the crate has been tipped to the position shown in Fig. I, and the weight of the engine is being carried entirely on the sling, the bolts which hold the engine to the mounting plate may be removed and the bottom of the crate drawn away from the engine.



Courtesy Pratt & Whitney
Fig. I

The spark plugs, or dummy spark plugs, and the sump drain plug should now be removed and the crankshaft turned over fifteen to twenty-five times by hand so as to be sure that there is no liquid in the combustion chamber. The spark plug should then be installed and the engine thoroughly cleaned with a spray gun, as previously described. Some manufacturers recommend washing the engine before it has been removed from the box. In any case, the steps described above should be done in a fairly warm place so that the oil on the inside of the cylinders will drain freely. The washing should be done preferably with white furnace oil, or Varno-



Courtesy Pratt & Whitney
Fig. II

line. After the engine is clean, the carburetor and any other accessories which do not interfere with the installation to the mounting ring may be installed. Every bolt and stud should be tightened and safetied before passing to the next, except where a series of bolts must be tightened gradually in sequence. In this case, they should all be safetied as soon as they have been tightened the desired amount. The engine may then be hoisted to the proper height for installation in the airplane. If a chain hoist is being used, the free portion of the hand chain should not be allowed to strike against the engine.

With the engine at the proper height, the airplane should be rolled to it with the tail up in flying position. (If the hoist is of the movable type, the engine may, of course, be moved to the airplane, in which case it should not be lifted more than enough for easy handling until it has been shifted to the proper location for installation.) With the airplane in the flying position, the engine should be carefully worked into the mounting ring, and the mounting bolts installed. As each bolt is passed through the mounting bracket the nut should be run on loosely to keep it in place. After all the bolts have been put in the holes, they should be tightened uniformly. It is desirable to tighten them in the same manner as propeller hub bolts; that is, when one bolt has been drawn fairly snug, the second tightened should be on the opposite side of the ring, the third approximately half-way between the first two, the fourth opposite the third, and so on. After they have all been tightened, the nuts should be properly cottered. The hoist may then be removed, due care being taken to see that the airplane does not nose over as a result of the weight of the engine. Sandbags or similar weights on the rear of the fuselage will eliminate this possibility. The various connections, for fuel lines, oil lines, instruments, etc., may then be made as instructed in the section devoted to these items. After the lines have been connected, but before the cowling has been put on, the ship should be wheeled out of the hangar and the engine given a test run as described in the chapter on top overhaul. All lines should be carefully inspected for leaks, chafing, or other trouble, and the engine washed off again before the cowling is installed.

COWLING

In its broadest sense, cowling is any falsework enclosure the purpose of which is to lessen the air resistance. However, it is usually understood, and will be considered in this book, to be a removable metal fairing around the power plant or cockpit.

The early airplanes had no cowling, the engine and occupants of the ship being left exposed to the breeze. As performance improved and greater speeds were attained, this arrangement was soon found to be both inefficient and uncomfortable. The advent of water-cooled engines brought radiators, which were set up in front of the cowling. It was then found that due to the thickness and inefficiency of the propeller blades near the hub, the radiator could be made smaller, and hence lighter, if placed somewhere other than between the propeller and the front cylinders of the engine. By decreasing the radiator area and streamlining the forward portion of the engine, resistance was lessened and performance proportionately increased.

When fixed radial air-cooled engines first came into use, designers were afraid to use any cowling around the cylinder heads lest the cooling be impaired. In fact, like most new things, air-cooled engines were regarded with more or less scepticism. The cowling covered only the crankcase and lower part of the cylinders while the rest of the engine was left exposed. The resistance of these exposed parts was, of course, high, and for a time it seemed likely that water-cooled engines would be restored to favor because of the possibility of keeping the resistance down.

However, experiments were made by various agencies, notably the National Advisory Committee for Aeronautics, and after much research the type of cowling for radial engines known as the N.A.C.A. cowl was developed. Practically all ships are equipped with this type of cowling today, as it reduces the drag of an air-cooled engine to approximately that of a liquid-cooled when the radiator is included with the latter. The liquid-cooled type still has the advantage if wing radiators are used but these are not practical for general use and are found only on racing ships such as the record-holding Italian Macchi.

<u>Cowl Fastenings</u> - Every airplane manufacturer has his own ideas about cowl fastenings, just as every make of automobile has its own type of hood latches.

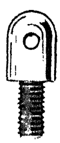


FIG. I.

However, there are certain fastenings which have become as nearly standard as anything in the industry and it is with these that this sheet deals. There are few airplanes in which they do not appear in one place or another. The cowling stud with the screw thread, shown in Fig. I, is a stock accessory which may be purchased from any dealer in aeronautical supplies. This type is machined from bar stock, is solid, and is usually made of steel. The installation is obvious, consisting simply of drilling a hole the size of the threaded portion, inserting the stud, and putting on a lock washer and a nut.

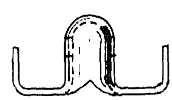


FIG. II

Another type is a hollow stamping, (see Fig. II) and is, of course, lighter than the threaded type. To install this type, three holes are drilled, one to fit the stud proper and the other two to fit the turned-up tabs. The stud is pushed through from the inside of the cowl support, the two tabs coming out through the holes which have been drilled for them. Then the tabs are bent down and the installation is complete, as shown in Fig. III.

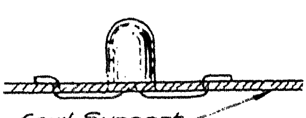


FIG. III

Where the cowling fits over studs, it will wear out rapidly unless the hole in the cowl is protected by a grommet similar to that in Fig. IV. Grommets are usually made of soft brass and then they become worn, they can easily be replaced. The installation is simple.

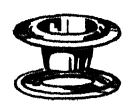


FIG. IV

hole is drilled in the cowl large enough for the shank of the grommet, the grommet pushed through from the outside, the washer slipped on the shank and the shank spread over the washer with a ball-pein hammer, or with a special grommet die, which makes a neater job.

FIG. V

The cowling is held in place with a cowling clip (see Fig. V) inserted through the hole in the stud, or if there are several studs in line, a similar device, but much longer and known as a cowling pin, is used. At points where it is extremely important that the fastening remain in place, a safety pin (Fig. VI) is used. An assembly of stud, support, grommet and cowl is shown in Fig. VII. There is no clip nor pin shown in this illustration, however.

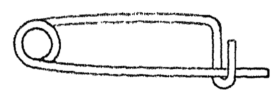


FIG. VI

When using a clip, it should be inserted in the hole until the first "hump" snaps over the cowl stud, and if possible the point should be toward the rear. It may not appear to be very secure fastening but it seldom comes out, and even if one should work loose there are usually plenty more to hold the cowl on.

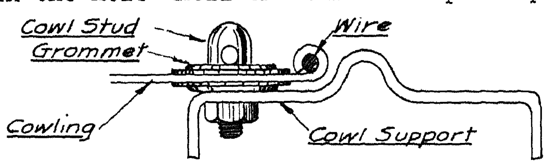
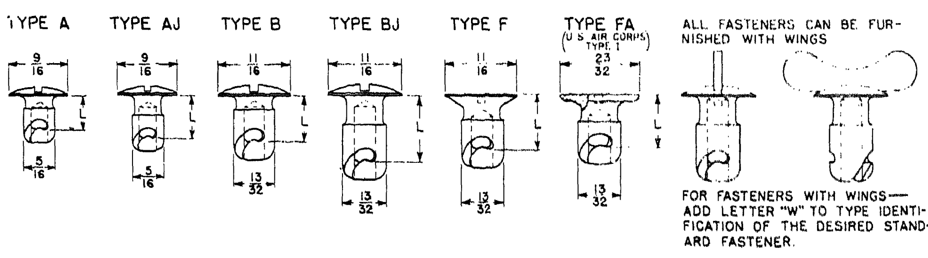
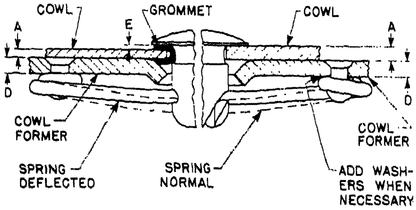


FIG. VII

One of the most satisfactory types of fastener is that made by the DZUS FASTENER CO., Inc., of Babylon, N.Y., by whose courtesy the illustrations in Fig. VIII are supplied. This fastener may be



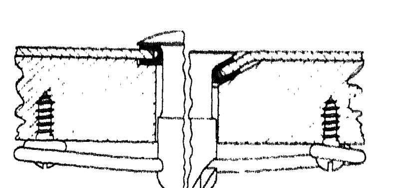


TYPE A & B INSTALLATIONS

LEFT SIDE— WITH GROMMET

RIGHT SIDE— WITHOUT GROMMET

THE REQUIRED LENGTH OF FASTENER = A + D + E + HEIGHT OF SPRING -- DEFLECTION OF SPRING. (OMIT "E" WHEN FASTENERS ARE USED WITHOUT GROMMETS)



TYPE AJ & BJ INSTALLATIONS

TYPE FJ INSTALLATIONS

IN THIN PLATE WITH STANDARD GROMMET

TO FIND REQUIRED LENGTH = FOR TYPES AJ & BJ USE SAME METHOD AS FOR TYPES A & B. FOR TYPE FJ USE SAME METHOD AS FOR TYPE FA.

installed so that it is absolutely flush with the cowl, and may be opened readily with a screw driver, or even a small coin, yet it holds securely when locked. It may also be obtained with a wing, which eliminates the use of any tools. It has no loose parts to be misplaced, is exceptionally neat in appearance and simple to install. The accompanying illustrations are self-explanatory.

Repairs on Cowling - There are several types of repair jobs on cowling which may become necessary from time to time. They may be grouped into three general classes:cracks, holes, and dents, the most common of which is shown in Fig. IX, which illustrates cracks beginning at the edge of a piece of cowl. Cracks may also start at the rim of a hand hole or any other place where it has not been desirable to roll in a wire as shown in Fig. VII.

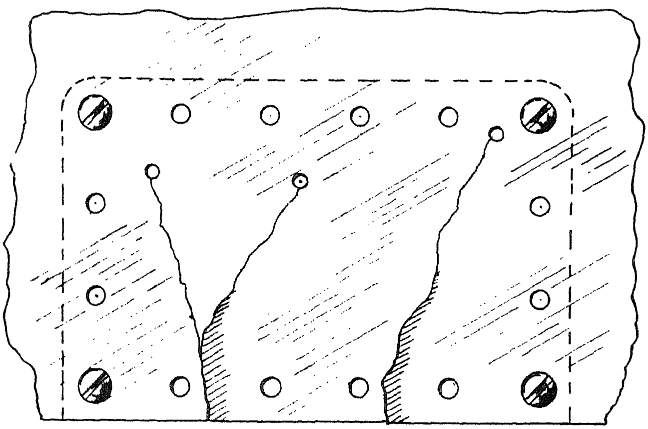


FIG. IX

Cowling should be inspected frequently for cracks and when they are observed no time should be lost in repairing them, as shown in Fig. IX. To begin with, holes of about 3/32" diameter should be drilled at the end of each crack to prevent its extending farther. A reinforcing plate of dural, of approximately the same thickness as the cowl and large enough to extend well beyond the damaged portion, should be riveted on the inside using small, flat head or binder head aluminum rivets with the head on the outside. Great care should be taken to prevent denting or bending the cowling when heading the rivets. It will be found helpful to drill the corner holes first and attach the reinforcing plate at these points with machine screws, which should be left in until the rivets have been headed in all the other holes.

Large holes in cowling do not usually occur accidentally, but are the result of some change such as the installation of a direct electric starter in place of a hand inertia type, which leaves the hole where the crank went through. Such holes should be patched following the same procedure as outlined above.

Dents in cowls should be carefully hammered out by placing the concave side of the dent on a smooth surface and tapping the convex side with a rawhide or wooden mallet. The paint will probably chip off during this process. The bare spot should be sanded, primed, and successive coats of sanding surfacer applied and rubbed smooth with fine sandpaper until the damaged area is no longer noticeable. Then the section should be sprayed with the original color. If sufficient

care is used, the job will be so completely disguised that it will be impossible to tell that any damage has ever been done.

FIRE EXTINGUISHERS

While fires in the air are fortunately not common, nevertheless on rare occasions they do occur. Obviously, it is next to impossible to extinguish a fire in the engine section while the ship is in flight with a hand extinguisher. To control such emergencies, various types of pressure fire extinguishers have been developed. The pilot or flight mechanic can operate these devices from the cockpit merely by pulling a handle. This operation opens a valve which allows the extinguishing medium to pass through pipes to the nozzles located at the various danger points and thus to be sprayed over the entire power plant.

The Lux Fire Extinguisher - A Lux fire extinguisher consists of three major parts: a cylinder of carbon dioxide gas held under a pressure of 850 lbs./sq.in., a control valve, and piping for distribution of the gas. Carbon dioxide is an inert gas in which flames cannot exist. It is non-poisonous and will not affect the pilot, nor will it wet or injure the engine in any way. As it leaves the discharge nozzles it forms a cloud of vapor and "snow" which is driven into all crevices by the slipstream.

As a rule, the tank is installed near the engine and the control is connected to the valve on the cylinder by flexible cable enclosed in 1/4" aluminum tubing. Fig. I shows the layout of a remote control Lux extinguisher system in a single-engine airplane, and Fig. II illustrates the layout for a twin-engine ship.

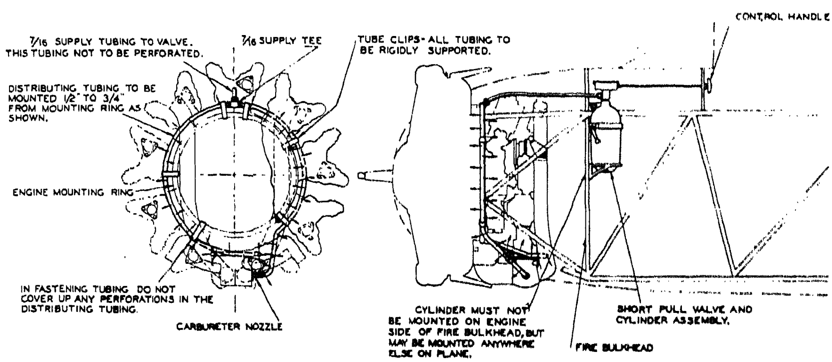


FIG. I

The Lux cylinder requires recharging only after use. The gas will not deteriorate with age nor freeze at any temperature above -110° F. An inspection window is provided on the valve to enable the mechanic to determine whether or not the cylinder is fully charged. If a cross is visible through the window it means that the cylinder is empty.

If desired, the operation of the extinguisher may be made automatic in conjunction with the Lux fire detector, a device which

indicates by means of either a visible or audible signal the presence of flame or heat in excess of 250° F.

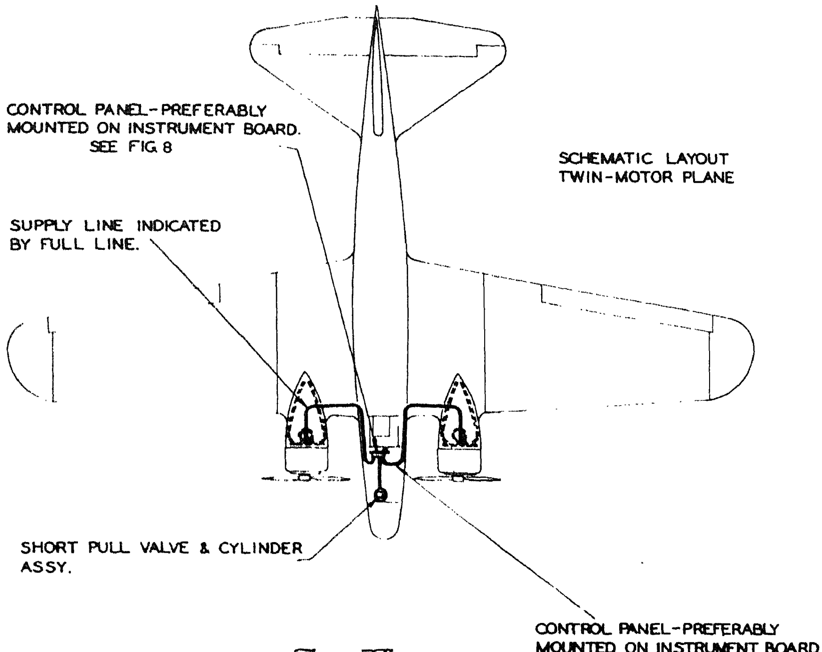


FIG. II

Operation of Lux Extinguisher - The operation of this extinguisher is simplicity itself. In the case of a single-engine ship it is necessary merely to pull a handle on the Lux control panel marked "Fire-Pull."

On a multi-engine airplane, set the distributing cock on the Lux control panel to the engine which is on fire, and then pull the handle marked "Fire-Pull."

Procedure After Use - When the system has been operated, the empty cylinder should be removed and recharged as soon as possible. On multi-engine airplanes the distributing cock should be reset to its normal central position. On all installations the control handle and cable should be set after working the cable back and forth a few times to make sure that it does not bind. The perforations in the distributing tubing around the engine should be inspected to see that they are not clogged and the tube plug at the ends of the tubing should be removed, any dirt or foreign matter cleaned out, and the plug replaced. The recharged cylinder should then be installed.

Installation of Lux Extinguishers - Detailed information on the installation of Lux Extinguishers should be obtained from the manufacturers, but every mechanic should be able to distinguish the two types of cylinders. One of these is designed to be installed in an approximate vertical position. It is identified by black dots on

the bottom and is marked with the letter "S" on the valve body. This type of cylinder is illustrated in Fig. III, which also shows the maximum angle at which it may be installed.

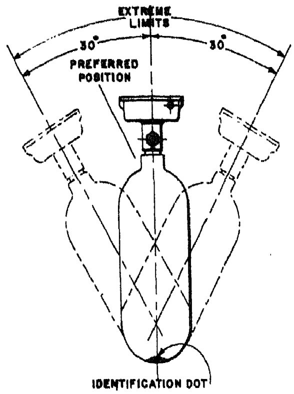


FIG. III

The other cylinder is intended for horizontal mounting and is identified with a black band 2" wide entirely around the cylinder and with the letters "S F" on the valve body. This cylinder is shown in Fig. IV.

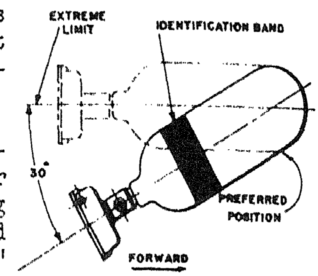
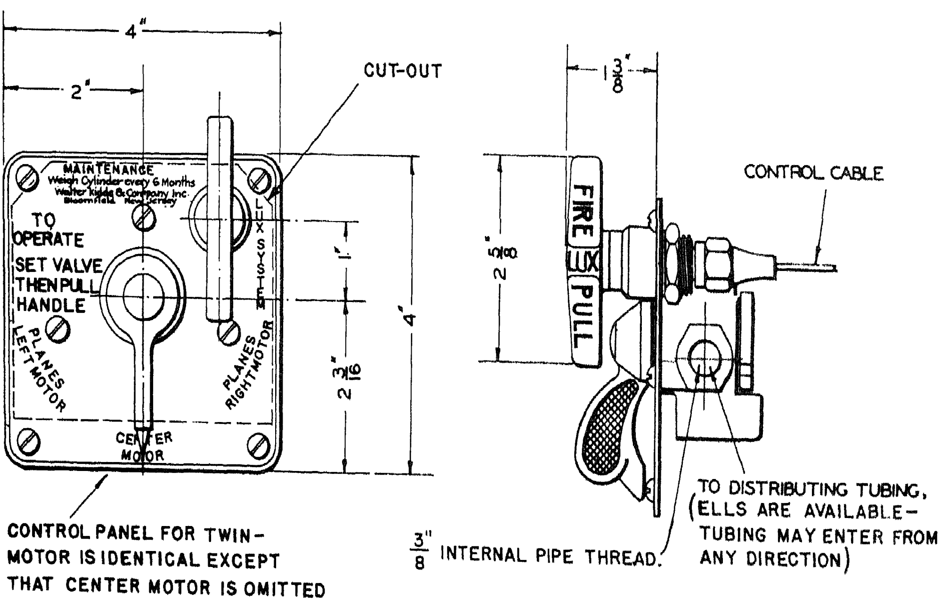


FIG. IV

A control panel for a three-engine airplane is shown in Fig. V. This panel is mounted on the instrument board with machine screws. The dotted line indicates the instrument board cut-out.



Maintenance of Lux Extinguisher - The maintenance of this extinguisher consists largely of testing at regular intervals. The manufacturers recommend that these tests be made once every four months and at a temperature of about 70° F.

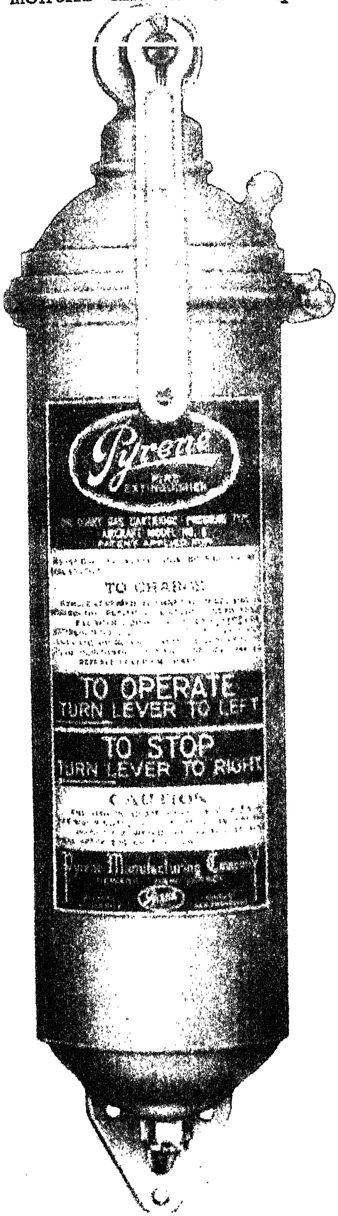


FIG. VI

The tests should be made with the airplane in flying position if possible. If the system is installed on a multi-engine ship, the distributing cock should be set to some one of the motors in order to provide an outlet for the gas.

A spring scale should be hooked over the pull handle and pulled with a slow, uniform force until the system is operated. The force required should not exceed 50 lbs. When the valve is opened in this manner, the gas should discharge about the motor and into the carburetor intake. In multi-engine airplanes this discharge should naturally occur around the motor to which the distributing cock handle is set. After the test, the discharged cylinder should be removed, recharged and replaced immediately. Recharging must be done by the manufacturer or by a regular recharging station. A record of the test should then be entered in the record card, stored in a slot under the name plate on the valve.

If the system is not discharged periodically every four months as just described, the cylinder should be removed and weighed at least every six months. If, when weighing the cylinder, it is found that the gas charge is less than the amount specified by 4 oz. or more, the cylinder must be recharged. The proper weights are stamped on the valve body.

The Pyrene Fire Extinguisher - The Pyrene Extinguisher is one of the most widely known types. It uses for an extinguishing medium carbon tetra-chloride, a harmless liquid which is highly effective in putting out fires. The company makes many models of hand-operated extinguishers, but in this discussion we are concerned with the pressure type only.

There are two models of Pyrene pressure fire extinguishers for aircraft

use, one of which, illustrated in Fig. VI, uses a cartridge of compressed carbon dioxide for expelling the liquid. The other uses compressed air. In the cartridge type, when the lever is turned the cartridge is punctured, releasing the pressure and at the same time the liquid outlet valve is opened and liquid passes out through a tube running to the bottom of the extinguisher and through a copper tube leading from the extinguisher to the carburetor or other parts of the power plants where fire hazards exist. A common procedure in installing the system is simply to close the end of the copper tube and drill small holes a few inches apart near the closed end, so that when the extinguisher is operated, the liquid is sprayed from these holes. Another type of installation uses special spray nozzles supplied by the manufacturer. This extinguisher can be operated by remote control if a rod or cable is extended from the operating lever to the pilot, so that by pulling on the rod or cable the system is operated. It should be remembered that in this extinguisher the liquid, and not the carbon dioxide, is the extinguishing medium.

The type which is operated by compressed air carries a pressure gage to indicate the air pressure inside the tank and is pumped up through a valve similar to an ordinary tire valve. It is operated by means of a valve wheel, which, when turned, permits the air to pass from the air chamber into the liquid chamber, and at the same time opens the liquid valve and allows the liquid to pass out through the discharge opening and thence through tubing in the same manner as the model previously described. The compressed air type may also be operated at a distance by attaching a lever to the valve wheel and connecting the lever to a handle in the cockpit by means of a rod. The rod is preferred to cable since it will enable the extinguisher not only to be turned on, but also to be turned off.

Recharging these extinguishers consists of simply filling them with Pyrene liquid and then replacing the cartridge, in the cartridge type, or pumping up the pressure in the air pressure type. Instructions for recharging are given on the nameplate of the extinguisher. Installation is extremely simple since each extinguisher is provided with brackets which may be bolted to the structure of the airplane.

PREPARING THE ENGINE FOR STORAGE OR SHIPMENT

If not properly protected, an engine will deteriorate more rapidly in storage than in actual use. Accordingly, the subject is one of great importance and in spite of the fact that it is not strictly a part of "installation", it is included here because it does not fit conveniently into other sections of the book.

Short Time Storage - By "short time storage" is meant storage for a period of not more than six months. If the engine is not installed in the airplane within this time, it should be unpacked and re-oiled and greased, as described below. If it is likely that the engine will not be put in service for more than six months, additional precaution should be taken as described under the topic "Long Time Storage."

To prepare the engine for storage, it should be mounted on a stand, and if possible located near a compressed air line and a

then be sprayed off with a cleaning fluid, such as white furnace oil, and dried with compressed air.

Long Time Storage - The operations previously described should be performed and in addition, before the valves have been greased the engine should be mounted on a belting-in stand. The engine should then be run by the belt for ten or fifteen minutes, using No-Oxide-EEE as a lubricant. This compound will be pumped through all the bearings and passages by the regular engine oil pump and will thoroughly coat all interior parts of the engine. After this operation, the suction line should be broken and about two quarts of warm oil drawn in through the engine pump. A warning tag should be attached to the engine underneath the wrapper, stating that it has been slushed and has heavy oil inside. Another method of lubricating the valve is to fill the rocker box with a non-corrosive grease and work the valve up and down by means of the simple tool and modified rocker box cover illustrated in Fig. I.

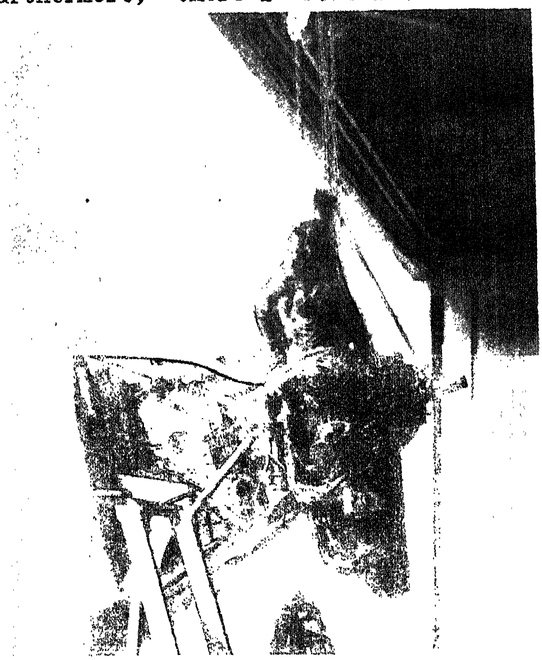
After the greasing has been carried out as explained above, the engine should be securely mounted in the box, covered with oiled paper, or oilcloth, and the cover of the box bolted down.

CHAPTER 16

TOP OVERHAUL

DISASSEMBLY AND OVERHAUL

As explained heretofore, a top overhaul calls for disassembly of the engine only as far as the crankcase. Most manufacturers, especially of the larger and more expensive engines, recommend the elimination of the top overhaul entirely, advising major or complete overhauls every three or four hundred hours. However, it is still common practice, particularly among small operators, to give top overhauls. Furthermore, there is sometimes a need for the overhaul of one cylinder when the others are in good condition. For these reasons, the procedure is discussed in the following pages. As to when a top overhaul is needed, this is usually indicated by loss of compression, or unusually high oil consumption. Also of course, a loss in r.p.m. when it is certain that the carburetor, ignition system and propeller are functioning properly.



Courtesy Pratt & Whitney Fig. I

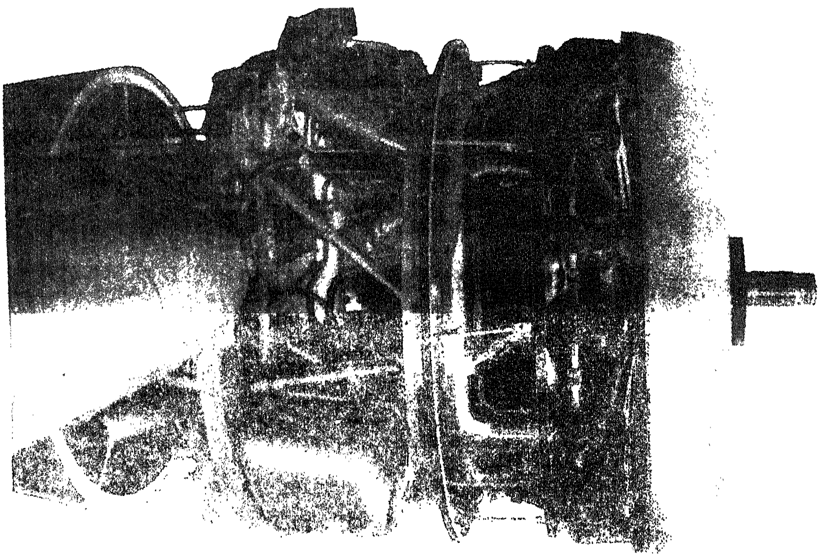
An engine may be given a top overhaul without removing it from the ship, but this practice is not recommended. The work may be done much more satisfactorily with the engine in the shop, and there is less likelihood of dirt getting into the open crankcase. The sequence of operations is given below. Detailed instructions for the various steps are taken up separately.

To remove the engine from the ship, a chain hoist or some other lifting device should be available. Also, of course, an overhaul stand to fit the engine and a hoisting sling such as that shown in Fig. I. A satisfactory sling can be made from heavy control cable. If the engine is not equipped with lifting eyes, a sling of the type shown cannot be used and it will be necessary to loop cable or rope around the bases of the two cylinders which are most nearly horizontal, being careful to lead the cable so that when the slack is taken up there will be no damage to intake pipes, push rods, or other parts. Take no chances on the strength of the rope or the security of the fastenings.

Remove all cowling, baffles, exhaust manifolds, the propeller, and disconnect all gas, oil, electrical, or other connections,

including, of course, the engine controls. Gas and oil lines should be plugged with corks or the open ends should be covered with a cloth tied or wired on, so that no dirt may get into the piping. The same applies to any openings into the engine. It is also desirable to tag the end of each connection, so that there will be no time lost in assembly tracing which line or wire leads to a given place, especially if the installation is one with which the mechanic is not familiar.

Roll the ship so that the engine is under the hoist, attach the sling and take up all slack. Remove the engine mounting bolts, un-



Engine Installation in Sikorsky S-43
Fig. II

less it is desirable to disconnect the whole engine mount from the fuselage and take it off of the engine later. In any case, whenever bolts are removed from the engine mount or anywhere else, they should be put back in the holes and the nuts put on as soon as possible, so that they will not be lost. The same applies to the nuts on studs, clevis pins, or any other small parts. When the engine is disconnected from the fuselage, unless a traveling crane or portable hoist is being used, the ship must be backed away. It may be necessary to lift the tail to work the accessories on the rear of the engine through the mounting ring. Also, it is often the case that the mounting bolts may be removed with less difficulty if the ship is in approximately the flying position. When the engine is clear, lower it and bolt it to the overhaul stand. Clean thoroughly, preferably with a gasoline spray, using a pressure of 150 lbs. if available. Before spraying, however, check the engine over again to make sure that all openings are plugged or covered, but never plug holes or

lines with rags, as they may be pushed inside and not be discovered when reassembling.

Do not attempt disassembly without the proper tools. Use only wrenches that fit the parts to be unscrewed and never use pliers on a nut or bolt. The engine tool kit usually contains any special tools, such as intake pipe wrenches, valve spring compressors, etc., that are needed for a top overhaul. Have a clean table or rack where the parts may be laid out in order, so that they may be reassembled in their original locations and positions. It is an excellent plan to tag each part as it is taken off.

SPARK PLUGS AND WIRES

The spark plugs should be removed with the proper type of wrench, and overhauled as explained in the chapter on "Ignition." The ignition harness should be removed, taking care to first disconnect all radio shielding ground terminals and to disengage all wires from their cylinder retaining clips. The inspection and overhaul of the ignition harness has been discussed previously, also in the chapter on "Ignition."

EXHAUST MANIFOLD OR RING

Ordinarily the exhaust tubing and pipes are easily removed, but occasionally difficulties are encountered when attempting to remove the nuts from the cylinder exhaust studs, or when attempting to loosen the exhaust slip joints. Brass nuts are customarily used on the cylinder exhaust studs so that there will be less likelihood that heat and oxidation will make them seize on the stud. Even so, there are times when it is impossible to remove these nuts in the conventional manner, due to the fact that, being soft, they become rounded easily. If the nut becomes rounded it may often be removed with a small four inch or six inch pipe wrench. Nuts which cannot be unscrewed may be cut off, using a sharp cold chisel. This practice should be followed only as a last resort, for there is great possibility of damaging the stud or cracking the base.

The following procedure when cutting a nut loose has proved very effective. Support one side of the nut with a heavy square-ended object and cut the opposite side, making the cut by using a sharp cold chisel having a blade width equal to the height of the nut. The cut should be started by holding the chisel at exactly 90° to the flat surface on the nut, and tapping it lightly a few times with a hammer. After the cut has been started, incline the chisel slightly, so that additional blows of the hammer will tend to loosen the nut. By this means it is often possible to unscrew the nut before it is entirely cut, thereby insuring that the threads on the stud will not be damaged.

There is not much that can be said about how to loosen a tight exhaust slip joint, except to caution against the use of any tools or methods that would result in permanent damage to the pipe. A good grade of penetrating oil can often be used to advantage, as it will help loosen the joint by attacking the oxidation.

Various types of exhaust systems are described in Chapter III.

INTAKE MANIFOLD OR PIPES

The intake manifold or the induction pipes should be removed, taking care to see that the proper type of wrench is used. Manifolds are usually attached with the conventional stud and nut fastenings, in which case standard wrenches can be used. Induction pipes are customarily attached by special packing nuts at the crankcase end. It is important that the wrench which is designed for this nut be used, as it is easy to damage the thin-walled induction pipe with an improvised tool. The special intake pipe wrenches are standard equipment in the engine tool kit. Fig. I shows the removal of an induction pipe on a Wright Whirlwind. Note the special intake pipe wrench. Caution: Many intake pipes are made of thin gage aluminum and can be seriously damaged by dropping.

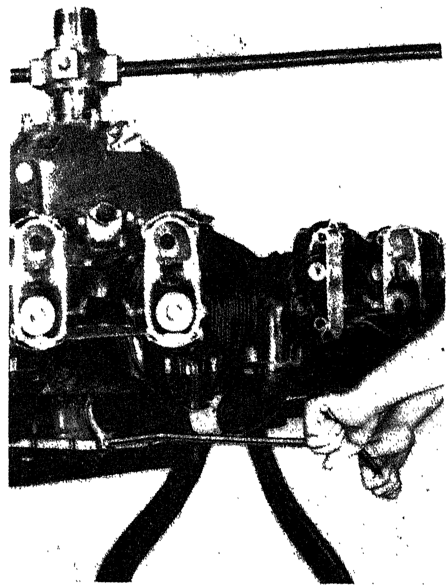


Fig. I
Removing Induction Pipe
Wright Cyclone

It is usually considered adequate to inspect intake manifolds or pipes visually to see that they are in good condition. If there is reason to believe that they have been damaged, the paint should be removed and the parts inspected minutely with a microscope. Leaks may often be discovered by filling the pipe in question with clean gasoline. Any large leaks will, of course, become apparent immediately.

It is customary to paint the intake pipes in the same manner as is done with cylinders, using the same kind of paint. (See Painting Cylinders, in this chapter.) Care should be taken when refinishing not to get any paint on the gasket or packing surfaces.

CONNECTIONS TO CYLINDERS

Before the cylinder can be removed, all of the connections from accessories to the cylinder, such as baffle plates, primer lines, manifold pressure ring connections, thermocouples, liquid connections, etc. should be taken off. These parts should be inspected visually to make sure that they are in good condition.

All parts, as they are removed, should be labelled or tagged so that there will be no confusion when they are reassembled. It is especially important to label the baffle plates, as many times they can be replaced only in one position, yet they look so nearly alike that much time will be lost searching for the correct baffle, unless it bears some identifying mark.

All electrical wires which are disconnected from the cylinders should be identified by tags, and, unless the battery has been removed, insulated or protected in some manner so that it will be impossible for them to cause a short-circuit.

Copper and dural tubing which has been disconnected should be labelled if there is any possibility of confusion when reassembling. The ends of the tube should be plugged, or otherwise protected from dirt or damage. No pipes, tubes, or engine openings of any kind should be plugged with rags or any other material which may leave foreign matter inside when the plugs are removed. A soft wood or cork stopper should be used for this purpose.

Push Rods and Housings - On the majority of radial engines it is unnecessary to remove any of the valve mechanism except the push rods and the pushrod housings before removing the cylinder. If such is the case, the parts mentioned may be removed by loosening the pushrod housing packing glands, using the special engine wrench designed for this purpose, and then depressing the valve spring. This allows the entire pushrod and its housing to be removed at the same time. Caution: Make sure the crankshaft is turned so that the valve is open before compressing the spring.

Some pushrod housings are made in two pieces telescoped at the middle, having the middle joint covered with a rubber sleeve. If this type of housing is used it should be compressed and locked before attempting to remove. This can be done by forcing the opposite ends together with the hands. After being fully compressed it may be locked in this position by twisting the sections in opposite directions.

CYLINDERS

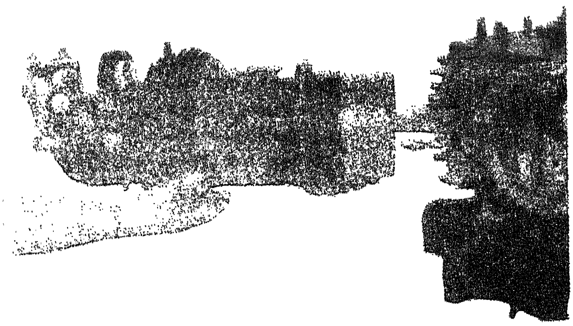
Removal:- The following procedure may be used as an outline for the sequence of operations in removing the cylinders from any engine in which the cylinders are not cast in a bank:

1. Turn the engine crankshaft until the piston in the cylinder which is to be removed is approximately on top center. Note: On radial engines this is usually indicated by the key way or wide spline in the crankshaft pointing directly to the cylinder. On many other types of engines the position of the piston may be located by inspection through one spark plug hole. Such inspection is often facilitated by shining a flashlight through the other spark plug opening.

2. Remove with pliers safety wire locking hold-down nuts. If "Palnuts" or some other form of lock nut or lock washer is used, there will be no wire, and the nuts may be removed with the proper wrench. Remove the nuts which are most difficult to reach first.

3. Slide the cylinder off carefully, as shown in Fig. I, taking care not to allow the wrist pin to fall out of the piston. Note: It is usually best to replace all of the cylinder hold-down nuts on the crankcase studs, thereby avoiding the possibility of misplacing or losing them. If this is not done the parts removed should be counted and stored systematically.

4. Lay the cylinder down and remove the wrist pin and piston. If the wrist pin is tight, tap it lightly, using a fibre rod or drift, or a round piece of wood. If light tapping does not move it, heat the piston carefully with the blow torch or with rags dipped in boiling water. Push the pin through only far enough to remove the piston from the connecting rod, then push it back into the piston. Mark the number of the cylinder and piston on a tag, or place in a numbered rack, so that there will be no confusion when reassembling. Most cylinders and pistons have numbers stamped on them, but they cannot be seen, in any case, until they have been cleaned.



Removing Cylinder Fig. I

The procedure for removing a cylinder bank is similar to the above. However, in addition to removing all cylinder accessories, connections, hold-down nuts, etc., the following precautions should be observed:

1. See that all tower shafts, gear trains, oil lines, pump connections, etc., are removed or disconnected. Note: Observe timing marks on all gear trains before disassembly.

2. Remove as much of the valve operating mechanism as possible, to reduce the weight of the cylinder bank. See "Removing Valve Mechanism."

3. Make sure that the engine is supported in such a manner that it will not become unbalanced and roll over when the bank is removed. This is especially important when working on a Vee type engine.

4. Before actually starting to remove the bank, be sure that there is sufficient assistance present to do the job. Many serious accidents have occurred as a result of underestimating the weight of a cylinder bank. When removing banks from larger engines it is often desirable to have a block and tackle, or at least a snubbing rope, attached in such a manner that the weight of the bank may be supported at any time. Caution: If such an arrangement is used it should never be used to pull the cylinder bank from the engine, but merely to support its weight.

5. When removing the bank, care should be taken to see that it is moved evenly, that is, one end should not be allowed to travel faster than the other.

6. Special care should be taken to support the block when it first

clears the hold-down studs, as there will be a tendency for the base to swing free, possibly crashing into the base studs and causing damage in the nature of bent studs, cracked case, or injured cylinder walls. Note the bench under the cylinder block in Fig. II.

. Before the bank is entirely removed some provision must be made to support the connecting rods so that the weight of the pistons will not cause them to fall against the side of the case when they are freed from the bank. One method of steadying the connecting rods is to bind them in a central position using heavy elastic bands anchored on the adjoining cylinder studs. Sections cut from an automobile inner tube will serve admirably.

3. After the bank is removed it should be stood on some clean wood blocks so as not to damage the flange surface. If it is to be laid on its side, make sure that no part attached to the bank will be injured.

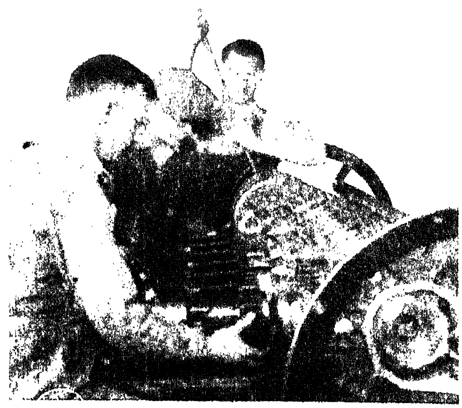
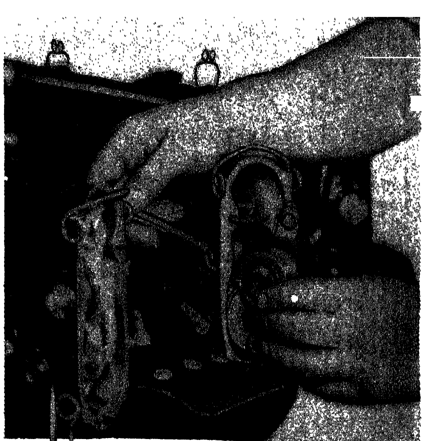


Fig. II
Removing a Cylinder Bank from a Curtiss Conqueror Engine

Removing Valve Mechanism - The removal of overhead camshafts can usually be accomplished by simply removing the bearing caps and lifting the camshaft off. However, it is important to remember that there will be considerable pressure on the shaft due to the fact that some of the cam lobes are holding valves open. Therefore, it is essential that all of the bearing caps be loosened gradually and equally, as otherwise the valve spring tension will impose a bending strain on the shaft.



Removing Rocker Arm Fig. III

The rocker arms may be removed from individual cylinders in most cases by removing the through bolt which serves as the rocker box axle. Sometimes this bolt is too tight to be removed with the fingers, in which case a fiber drift may be used. Fig. III shows the removal of a rocker arm from a Wright Cyclone.

The method of removing valves varies with different engines. In some, the valve spring retaining washers are screwed onto the

valve stem, but in most cases the end of the stem is grooved to receive a split cone, the outside of which fits a conical depression in the washer. The force of the valve springs holds the washer in place and it in turn holds the split cone in the groove. Some valves can be removed without removing the rocker arm and some cannot. In practically all cases, however, it is necessary to use a block of wood at least 2" thick and slightly less than the cylinder bore in width. The length should be slightly more than the length of the inside of the cylinder, the upper end should fit the inside of the cylinder head, and at the lower end it should be fastened to a block from 4" to 6" square so that it will stand upright. The purpose of this device is to keep the valves against their seats when the spring is compressed, as shown in a, Fig. IV. This picture also serves to illustrate the special valve removing tool used for the Wright engines. Fig. V shows a similar tool designed for the Pratt & Whitney engines. It will be noticed that in the latter case the valve is removed before the rocker arm.

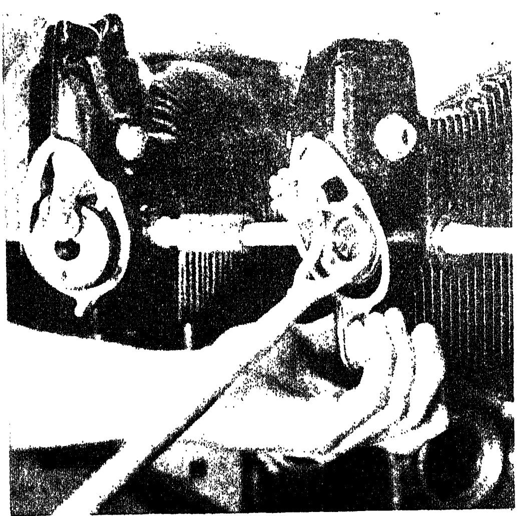
Courtesy WRIGHT AERONAUTICAL
Fig. IV

The following procedure applies in general to removing any type of valve:

1. Set cylinder on valve removal block.

2. Compress valve spring with compressor and pick out split cones with long nose pliers.
   CAUTION: Be careful of getting the fingers caught if pliers are not used. (In an emergency, the spring may be compressed with an open end wrench, but it is a two-man job and not recommended.)

3. Remove springs and washers and tie together. Wrap split cones in small rag and tie to springs, so that they will not be



Courtesy PRATT & WHITNEY

Fig. V

lost. Tag springs or lay out so that they may be replaced in original location.

4. Remove small safety ring on valve stem and tie to springs.

5. Hold valve stem, remove cylinder from block, reach inside cylinder with other hand and remove valve. Mark or lay out valve so that it may be identified.

6. Repeat procedure with other valve in same cylinder.

Fig. VI suggests one method of keeping the valves properly identified.

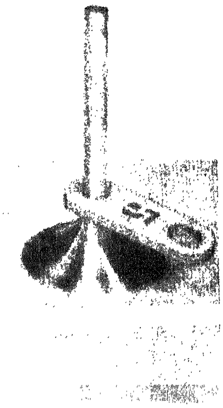


Fig. VI

Cleaning and Painting Cylinders - After the valve mechanism has been removed, the cylinders should be cleaned thoroughly, both internally and externally. This operation affords an excellent opportunity to inspect visually the condition of many items, such as the cooling fins, the rocker cap hold-down studs or spring clamps, the intake flanges, the exhaust flanges, all bushings and similar parts.

The carbon should be removed from the inside of the cylinder head with a metal scraper. Great care should be taken not to injure the valve seats or to gouge the aluminum head. After the carbon has been removed the interior of the head may be polished by using fine emery cloth, saturated in cylinder oil. Caution: Do not use this abrasive on the valve seats or cylinder walls.

If the enamel on the outside of the cylinder is in good condition and is not to be removed, the entire cylinder may now be cleaned, using a gasoline spray gun. After allowing it to dry, all of the machined surfaces should be protected with a film of light oil. If the cylinder is to be repainted it is preferable to remove all of the old paint, as several coats of paint will seriously affect the cooling of the cylinder.

One of the most effective methods employed to remove paint is sand blasting. If such equipment is to be used, the cylinder must first be protected against damage by the sand. The intake and exhaust flanges should be covered with heavy cardboard gaskets, the spark plug openings should be plugged, and all studs and machined surfaces covered with masking tape or a heavy grease. The cylinder paint can be removed by hand, but it is a long tedious job, especially if the cylinder is finned. In any case, all traces of the old paint must be removed and the surface left free from oil, grease or dirt. Note: The cylinders should not be painted until after they are inspected and overhauled.

The most satisfactory method of painting a cylinder is to use a spray gun, Fig. VII. The paint used should be of the finest quality and must be heat-resistant. One of the best paints made for this

purpose is manufactured by the Hilo Varnish Corporation of Chicago. The following procedure is recommended when using their products:

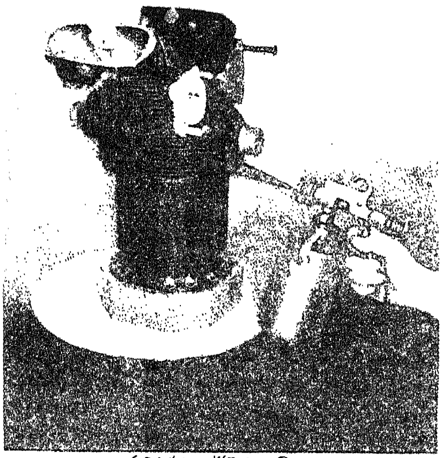
1. Clean the cylinder thoroughly and protect all parts not to be painted. Spray on one coat of Hilo Number 938.

2. Bake in a well ventilated oven for two hours at 425° F. and then for three hours at 400° F.

3. Let the cylinder cool and spray a second coat, using Hilo Number 934.

4. Bake again, as in step No. 2.

This will produce a finish similar to that found on a new cylinder.



Courtesy Wright Aero

Fig. VII

<u>Inspection of Cylinder</u> - In addition to being inspected visually for any signs of chips, cracks, dents, broken fins, etc., a cylinder should be tested for the following:

1. Loose or worn valve guides
2. Loose or damaged spark plug bushings
3. Cracked rocker boxes
4. Loose studs
5. Loose primer connections
6. Loose, pitted or damaged valve seats.
7. Scored, pitted or worn cylinder walls.

The cylinder barrel may be checked with an inside micrometer or an inside dial indicator micrometer, as illustrated in Fig. VIII, for excessive wear and for an out-of-round condition. The engine handbook should be consulted for tolerances.

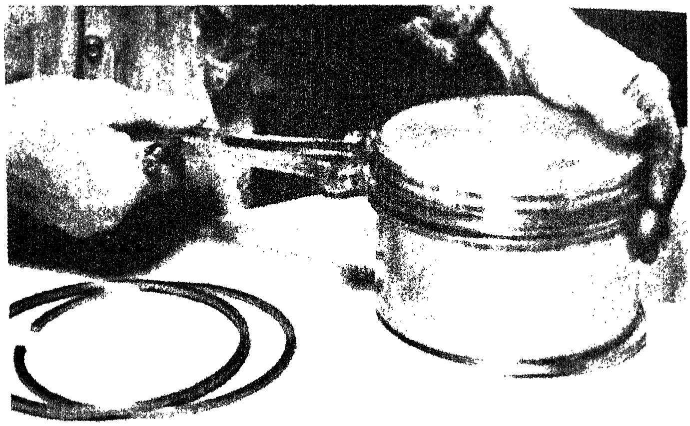
If any of the above-mentioned faults are found, or the tolerances are exceeded, the cylinder should be repaired by the factory or an approved overhaul station, or discarded at their recommendation.

Checking Cylinder Bore

Fig. VIII

PISTONS

<u>Removal</u> - Most pistons are attached to the connecting rods by a



Using Ring Extractor
Fig. I

full - floating or semi-floating wrist pin. In the first type, the wrist pin is held in position by a soft metal pad at either end while the second employs a safety ring at each end of the pin for the same purpose. If pads are used it is not necessary to remove them before removing the piston pin, however if they are loose, as is sometimes the case,they may be removed simply to prevent them from falling. Safety rings should be removed before attempting to remove the pin. If the pin is tight in the piston, do not attempt to drive it out, but heat the piston with rags soaked in boiling water. A blow torch may be used to heat the piston but great care must be taken to avoid damage. After the piston is expanded the pin should slide out. If it doesn't it may be tapped lightly, using a soft-faced drift. During this operation the connecting rod should be supported to relieve any bending strain imposed on it by the hammer blows.

The wrist pin and piston should be marked in some suitable manner so that the pin may be replaced in its original position in the correct piston.

Cleaning - Before cleaning the piston, the rings should be removed with a ring expander (See Fig. I). If no ring expander is available three strips of aluminum about 1/2" wide may be worked under the ring so as to hold it out of the groove. Caution: The edges and points of the rings are extremely sharp and care should be taken not to cut the hands or gouge the side of the piston.

Scrape the carbon from the top and sides of the piston with an aluminum scraper, taking care not to scratch the piston. The carbon should be cleaned from the ring grooves with a broken ring ground to a chisel edge (See Fig. II), caution being taken not to widen the groove or damage the edges. Fine sandpaper (3/0 or finer) may be used to polish the top of the piston but not the sides. All loose carbon, dirt and sludge should be cleaned from the inside of the piston with an aluminum scraper.

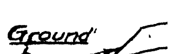
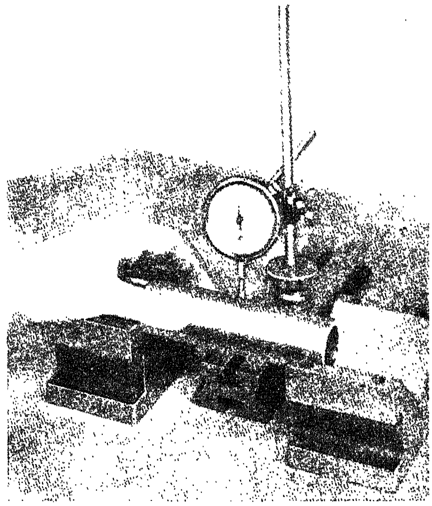


Fig. II

Frequently the small oil holes in the piston (at the bottom of the ring grooves) are plugged with hard carbon, in which case they can be cleaned readily with a small twist drill operated by the fingers. Needless to say, the drill selected should be slightly smaller than the diameter of the oil holes. Clean gasoline should be used to remove all traces of oil, dirt, or sandpaper dust.

Inspection - The piston should be inspected for scores, cracks, or damages of any kind. If the marks are not over a few thousandths of an inch deep, they should be removed with an oil stone. Deep scores or cracks mean that the piston should be discarded. The piston should be checked with a micrometer for the dimension tolerances as specified in the engine handbook.



Checking Wrist Pin Fig. III

Check the trueness of the wrist pin with a dial gage (See Fig. III), and consult instruction book for the proper diameter and piston clearance. If it is too loose in the piston it will be necessary to have an oversize pin installed by an authorized repair station.

FITTING PISTON RINGS

Although it may not be absolutely necessary it is customary to install new piston rings when the cylinder is taken off. If the engine has had much time, oversize rings which have been ground to the proper clearances should be used. The engine instruction book should be consulted for the proper clearances; however, if no book is available, the ring should be given approximately .003" side, or groove, clearance and a gap, or end, clearance of about .0035" for each inch of cylinder bore. Note: These figures are approximate and should not be relied upon except in case of emergency. Remember that it is much safer to have too much clearance than too little, for when the engine becomes hot, a tight piston ring may expand sufficiently to break or seize on the cylinder wall.

Checking Side Clearance
Fig. I

Check each piston ring for

side clearance in the ring groove. This is done with a feeler gage of the proper thickness as illustrated in Fig. I. A variation of more than .003" in width of the groove makes it advisable to have the groove re-cut.

If the side clearance is not sufficient the ring must be ground to the proper thickness. With proper equipment this may be done on a magnetic grinding wheel; however, it may also be done satisfactorily on a surface plate. To use the latter method, spread a thin, even coating of valve grinding compound on a piece of plate glass. Lay the ring flat on the glass and grind it down using a circular motion. This operation is much easier on the fingers if a tool is made by turning a groove to fit the ring, when compressed, in a blank coupling. A cross section of this tool is shown in Fig. II. The groove should not be as deep as the thickness of the ring. When using this tool the groove should be cleaned every time before the ring is replaced, as otherwise uneven grinding may result. Grind one side of the ring only.

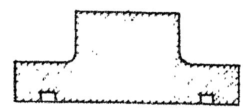


Fig. II

At frequent intervals during the grinding process the ring should be cleaned, installed in the proper groove and the side clearance checked. When the correct clearance is reached the ring should be left in the groove with the ground surface toward the top of the piston, until ready to fit the gap clearance. Precaution should be taken to make sure that each piston ring is eventually replaced in the groove to which it was fitted.

Checking Gap Clearance
Fig. III

The rings should now be checked for gap, or end, clearance by putting a piston into the cylinder and sliding the ring in until it lies on the piston. The piston is used merely to insure that the ring will lie straight across the cylinder. After making sure that the ring is flat on the piston, determine the ring gap with a feeler gage, as illustrated in Fig. 3. Ordinarily the ring is checked somewhat further in the cylinder than is shown in this illustration. Care should be taken not to force the ring apart when using the feeler gage. Caution: Never put a piston into a cylinder if any rings are installed as it may slip down so that the ring expands into the combustion chamber. If this happens the piston cannot be removed without damage.

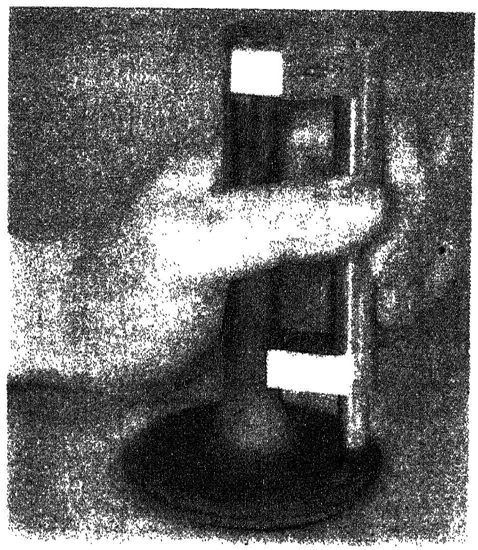
If the gap clearance is too small, one end of the ring should be filed carefully with a fine

single-cut flat file. Great care should be taken to make sure that the file is kept absolutely parallel to the surface. The clearance should be tested frequently until the specified amount is obtained. If the piston ring is of the offset, or step-cut type, it should be fitted by filing each long end an equal amount. Never file in the notch.

When all rings have been fitted and installed, the wrist pin should be slipped back into its original position and the piston wrapped in an oily cloth until it is ready to be assembled to the connecting rod.

VALVES AND VALVE OPERATING MECHANISMS

It is assumed that the valve mechanism has been disassembled and the parts cleaned, as previously described. All parts should be inspected visually for checks, cracks, corrosion or excessive wear. It is desirable to consult the engine manufacturer's handbook to ascertain the particular items to be inspected and the approved method for doing so. However, in general, the following instructions are applicable to most engines.



Testing Valve Stretch and Warp
Fig. I

Valves - The valves should be inserted in their respective guides and inspected for excessive play. If they fit too loosely in the guide it probably means that the valve guides will have to be replaced. Such work should be done by the factory or an approved repair station. Valves should be inspected for loose end plugs, and burned or pitted faces. In most cases, if the exhaust valve is pitted at the point where the head joins the shank, it should be discarded. The valve stem should be inspected for any indications of scores or chattering. If any deformations on the stem cannot be removed by polishing with fine crocus cloth, the valve should be replaced with a new one. The valves should also be inspected for stretching or warping, using a special measuring device, similar to that shown in Fig. I. If a tool similar to this is used, make sure that the guide pin is located in the proper groove. Hold the instrument as shown and rotate it completely around the valve. If the gage fails to touch the under side of the heat by as much as 1/32", it is an indication that the valve is either warped or stretched, in which case it should be replaced.

If the valve and seat are in good condition, the valve may then be ground. Most factories and large repair stations have automatic power machines for this purpose, but the average mechanic will

probably have to do the job using a conventional hand valve-grinding tool.

Grinding Valves - To grind, or lap, valves, spread a thin, even coat of valve grinding compound on the face of the valve and insert it in the guide. A thin coat of cylinder oil should be put on the stem before it is inserted in the guide, as this will lubricate the stem and prevent the compound from cutting it, and also will tend to keep the valve more nearly centered during the grinding process. Clamp the end of the valve in a valve-grinding tool, (Fig. II).

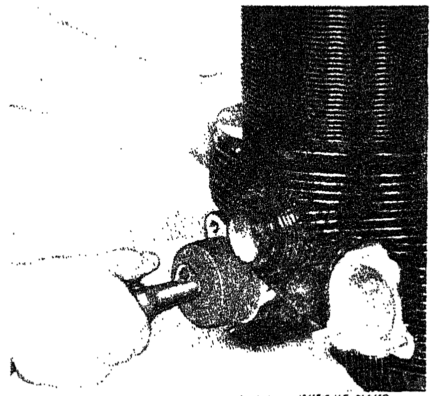
Grinding Valve
Fig. II

Holding the cylinder and the grinding tool as shown in Fig. II, pull the valve lightly against the seat. Rotate back and forth turning the tool 180° and taking a fresh grip every four or five strokes. Each time the grip is changed the valve should be pushed away from the seat and then pulled back as before. By so doing, the grinding compound becomes equalized on the surfaces, reducing the possibility of "ringing" the face.

At frequent intervals during the grinding, remove the valve, wipe off the compound and inspect. The grinding should be continued until there is a uniform gray band completely around the face of the valve. Before the valve is tested it should be given a final grinding, using the finest grinding compound and very light grinding strokes. If water-mixed grinding compound is being used, the final cut should be made with the compound well saturated with water.

The valve should be tested by assembling it in the cylinder (see Assembly of Valve Mechanisms, later in this chapter), using the retaining washers and springs. If the valve is to be removed it is not necessary to install the safety ring, however, as a safety precaution, it is a good plan to replace the safety ring in case the valve does not have to be removed. Where facilities are available, the valve should be tested by closing all cylinder openings and placing the cylinder in a pressure testing block. Fill the valve port with gasoline and then introduce the air pressure to the interior of the cylinder. Any leaks around the valve will immediately become apparent by the air bubbling through the gasoline. If no such facilities are available the valve seal may be tested by pouring gasoline into the valve port and, with a light, inspecting the valve from the inside of the cylinder to detect any gasoline leaks. If the valve has been put in dry, any leaks will become apparent immediately. If the face was oiled before the valve was assembled, a slow leak may not be detected until after three or four minutes have elapsed. Ordinarily, if no leaks appear within five minutes, the valve is considered to

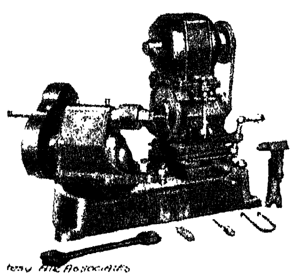
be tight. Another method used to test the valve seal is illustrated in Fig. III. The cylinder is inverted after the valves are replaced and the spark plug openings are closed. Enough gasoline is poured into the cylinder to cover the valve heads. Using a special plug as shown in Fig. III, compressed air is introduced into the port until a pressure of not less than 10 pounds, nor more than 15 pounds is obtained. Any leaks will become apparent as air bubbles in the gas. The gasoline used for testing may now be emptied and the valve assembly removed and stored until ready for final assembly. Caution: If the valve is not to be removed, it should be depressed slightly and the face coated with light cylinder oil to prevent rusting.



Courtesy Wright Aero.

Testing Valves
Fig. III

Refacing Valves - Valves which are in good condition except for pits on the face may be reclaimed by refacing them, using a standard aircraft valve refacing grinder, similar to the type shown in Fig. IV. Complete instructions for the refacing of valves are furnished with the machine which, if followed carefully, will insure an excellent job. The main things to remember are that the valve must not be warped, and that as little metal as possible be removed when the cut is made. Other contributing factors are simply the requisites of any good workmanship; a true stone, careful adjustments, etc.



tesy Air Associates

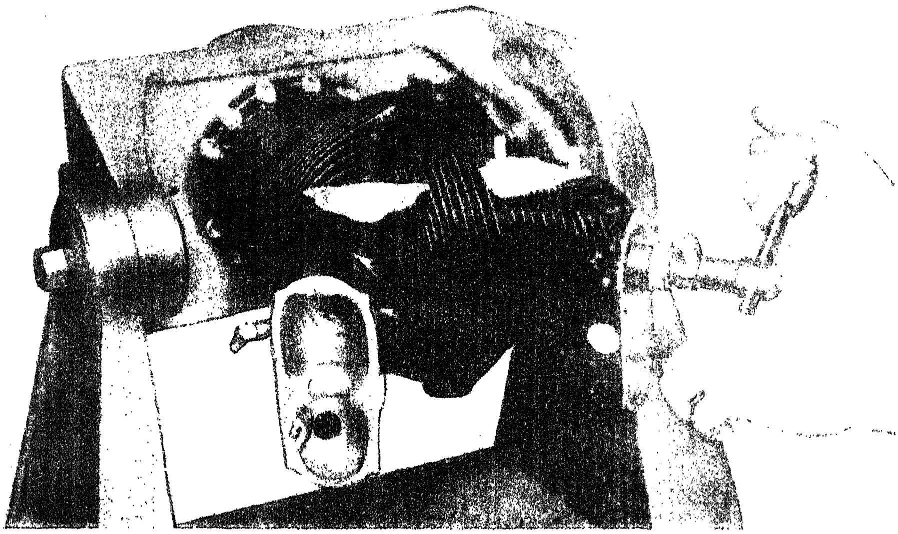
Valve Refacing Machine
Fig. IV

Courtesy of Air Associates Inc.

Valve Reseating Set
Fig. V

Recutting Valve Seats -Valve seats which are slightly burned or pitted may be reseated with a reseating reamer. A set of reamers designed for this purpose is shown in Fig. V. Before cutting a seat it is important to make sure that it actually needs it. Often a valve seat becomes discolored, due to a particle of carbon which has been hammered into its surface. This may give the appearance of a burned or pitted spot, but by testing with a correctly shaped scraper (or by making a trial cut using grinding compound and a valve) any surface discoloration will be discovered.

A reamer should be selected which has the correct cutting angle as specified by the engine manufacturer and, using the adjustable tension handle, a light cut should be taken from the seat. Considerable skill and trade judgment are required to use reamers correctly and for this reason the beginner should never attempt to recut valve seats except under the direct supervision of an experienced mechanic.



Courtesy of Wright Aeronautical Corp.

Fig. VI Recutting Valve Seat

When cutting with a reamer, Fig. VI, the adjustable handle must be set to provide sufficient tension to insure that the reamer will cut through the scale or hardened surface of the seat and still not remove any excess metal. If the blades are allowed to drag over the glazed surface they will become dulled or chipped. Turning a reamer backward may also dull or damage the cutting blades.

Some engine manufacturers recommend that the valve seat be as wide as the valve face and some prefer to have it narrower, however, in no case should it be wider. If the seat becomes too wide it may be narrowed by using two cutters with different angles. For example, if the 30° seat on a Wright Cyclone is too wide it may be reduced in width by using a 20° and 70° cutter as shown in Fig. VII. The final

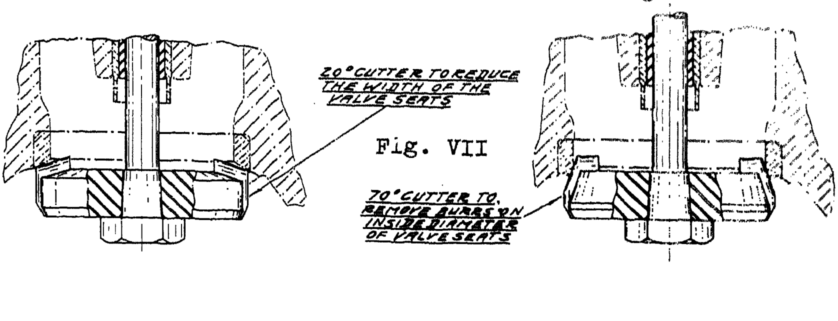


Fig. VII

cut should be made by using a 30° reamer, as shown in Fig. VIII.

Caution: The angle of the seat and the angles of the narrowing cutters do not necessarily apply to any other type engine. The individual engine specifications must be consulted for this information.

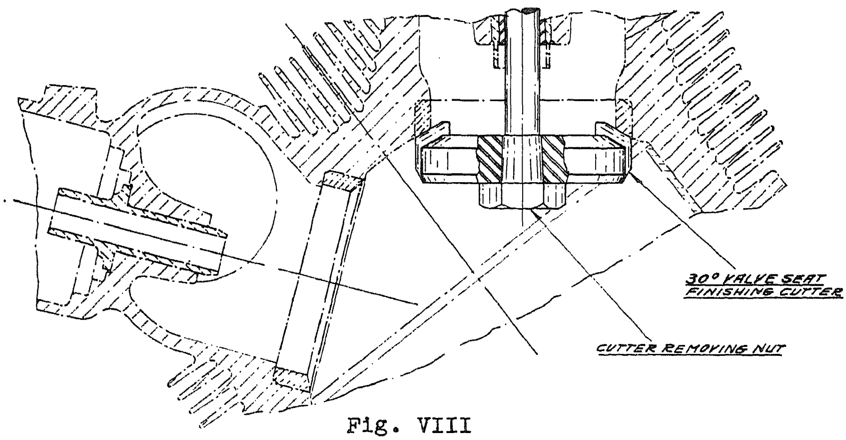


Fig. VIII

Retaining Washers - These should be inspected for cracks, rust, or undue wear. Cracks are most likely to develop near the fillets on the spring side.

Valve Springs - Inspect the valve springs for cracks, scores, pitting, or breakage. Ordinarily, a breakage at the tapered end of the wire does not seriously affect the efficiency of the spring. If proper equipment is available the tension of each spring should be tested as illustrated in Fig. IX. Proper spring tension will be given in the manufacturer's instruction book. If the proper tension testing equipment cannot be had or improvised, the equalization of the tension of the various springs may be checked by placing them in a row on a flat surface. This provides an opportunity to inspect at a glance the comparative length of each spring. Short springs are indicative of a lowered tension.

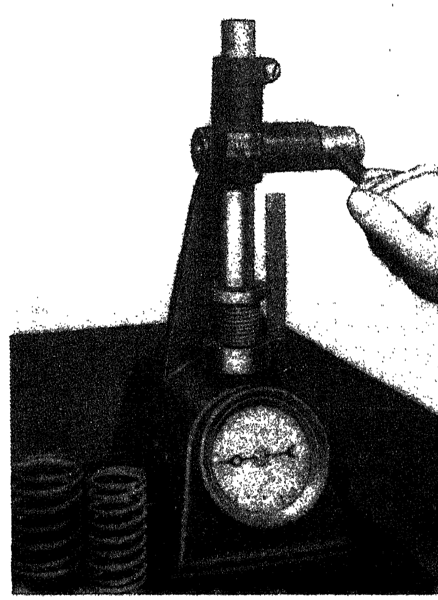


Fig. IX Testing Valve Spring Tension

Rocker Arms - Rocker arms should be checked for cracks, dents,

rust, or other damage. Cracks are most likely to develop at the radii or fillets. The condition of all threads should be inspected. The push rod seat should be inspected for indications of excessive wear or hammering. If it has been lightly galled, it is usually permissible to polish the surface with fine crocus cloth. Check the adjusting screws for the condition of the threads, the spherical seats and oil holes. As a safety factor, all lock washers on adjusting screws should be replaced. If a roller is used it should be checked for excessive play, cracks, rust and flat spots. Any roller or ball bearings should be inspected by first removing all grease or grit with clean gasoline. If, when perfectly clean, the bearing does not rotate smoothly it should be discarded.

Push Rods - Check the push rods for loose or damaged ends. Push rod ball ends should not be replaced unless so recommended by the manufacturer. Roll each push rod on a surface plate to see if it is straight. If any slight bend is apparent, the push rod may be straightened by tapping the high spot back into place with a light, soft-faced mallet. Ball ends may be polished with crocus cloth and any slight irregularity may be honed smooth with an oil stone.

ASSEMBLY

Assembly is one of the most important phases of top overhaul and should be done with the utmost care and skill. No specific directions can be given which will cover all cases, but the sequence herein outlined has proved to be applicable to most engines. Some of the most important things to remember are as follows:

Make sure that all parts are clean and free from any grit or particles of steel wool.

All steel parts should be oiled or painted, as the case may be, to protect them from rust.

All moving parts should be protected from the effects of friction by a coating of oil. In this connection it is well to remember that light cylinder oil will drain from an object in a short time, therefore if the engine is not to be run for an appreciable length of time after assembly, it is advisable to lubricate all friction points with castor oil.

It is essential that all safeties be replaced as each particular job is completed, to prevent the possibility of forgetting to safety any part. All cotter pins should be replaced so that they are tight and cannot chatter. This is particularly important on cotter pins inside the engine, for they cannot be inspected regularly. Because of their extra strength, it is customary to use steel cotter pins in places where they receive lubrication, such as inside of a pressure lubricated rocker box.

Valve Mechanisms - The first step in assembling the valve mechanism is to clean the valve thoroughly in gasoline. It should then be coated with light cylinder oil, especially on the stem and the face. Clean and lubricate the valve guide bore. Insert both the intake and the exhaust valves, attach their respective safety rings and, holding them in position by the ends, invert the cylinder over the block which was used to support the valves when they were removed.

Replace the lower retaining washers, making sure that the grooved side is up. Replace the valve springs, making sure that the correct springs are used for each valve. Replace the top retaining washer and, compressing the spring with the same tool as used when removing, insert the keepers. Note: Where possible, long nose pliers should be used to install the keepers to prevent accidental injury to the fingers. .

The cylinder may now be lifted off the block and the valve assembly tested by striking the top of the valve stem a few sharp blows with a soft-faced hammer. Any misalignment of the springs or retaining washers will probably be apparent.

Rocker Arms - The rocker arms should be assembled in the reverse order to that in which they were removed. Care should be taken to see that all moving parts are lubricated. If the rocker arm is of the type that is drilled for pressure lubrication, it is desirable to fill it with oil before assembling. Before safetying, the rocker arm should be tested for free action and end play.

Camshafts - After all the valves have been assembled the overhead camshaft may be replaced. Note: If cam followers are used, they should be lubricated and installed before the camshaft. It is important to remember that the camshaft should be placed in such a position that as few of the cams as possible will force valves open when the shaft is drawn down. After placing the camshaft in position all of the bearing caps should be installed and tightened evenly. This is to prevent any undue bending strain being placed on the shaft or any of the bearings. If dual camshafts which are made with an integral timing gear are used, the gears must be correctly meshed with each other before the shafts are installed. This is usually indicated by two marks on adjacent teeth of one gear and a mark on one tooth of the opposite gear. Naturally, they are to be replaced so that the single mark falls between the two marks.

Pistons - Pistons should be cleaned thoroughly in gasoline and allowed to dry before installing the rings. Great care should be taken to make sure that the rings which were fitted for the individual grooves be replaced accordingly. Be sure that no ring is replaced upside down. Note: Rings which have been ground should be replaced with the ground side up. Beveled oil wiper rings should be replaced with the beveled side up (toward the top of the piston). After all the rings have been replaced they should be lubricated generously with the correct grade of cylinder oil.

The piston may now be assembled on the connecting rod. Make sure that the piston is on the correct rod and in the correct position. Ordinarily, the cylinder number is stamped on the propeller side of the piston. If the engine has individual cylinders it is necessary to replace only one piston at a time, the cylinder following immediately. It is an excellent practice to fill the wrist pin with lubricating oil before installing the piston, as this insures adequate lubrication of the cylinder walls when the engine is first started. If the wrist pin is held in position by safety rings, the rings should be replaced as soon as the assembly is attached to the rod.

Cylinders - Before the cylinders are replaced the following preparations should be made. If cylinder gaskets are used they should be attached to the crankcase by a light coat of gasket shellac or other type of seal as preferred by the mechanic. The top of the cylinder gasket should not be shellacked, but should be coated with a non-adhesive seal, such as soft soap. The cylinder walls should be generously lubricated with the correct type of cylinder oil. The rings on the pistons should be so arranged that the gaps are spaced, as nearly as possible, evenly around the circumference of the piston. Many mechanics do not think it advisable to space the rings so that a gap is in line with either end of the wrist pin.

Individual Cylinders - If the cylinders are to be assembled to a radial engine, the master cylinder should be put on first, as this will prevent excessive rotation of the master bearing which might cause the pistons in other cylinders to exceed their normal travel. On some radial engines it is desirable to install the induction pipes before the cylinders. This can be determined by the method in which they were removed. The installation of induction pipes is discussed later in this chapter. It is very difficult for a mechanic to

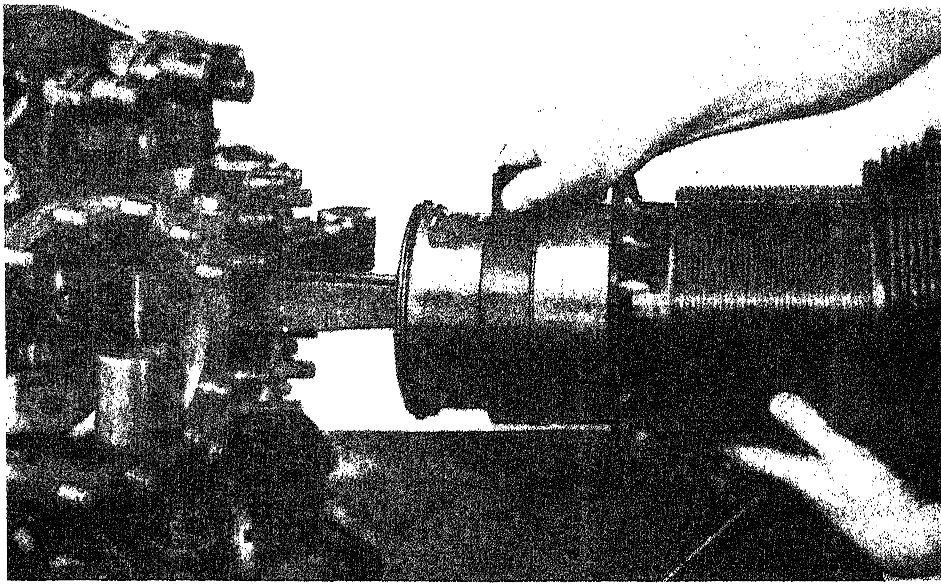


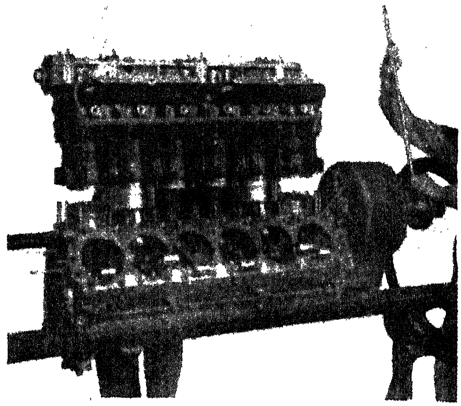
Fig. I Installing Piston and Cylinder

install a cylinder on a piston unassisted unless a ring compressor, such as illustrated in Fig. I, is used. This tool can be improvised from a sheet of thin metal, and reduces the possibility of ring breakage.

Holding the piston and cylinder as illustrated, gently work the cylinder over the piston rings, then slide it down as far as the wrist pin. At this point the wrist pin safeties should be again inspected just as a final check. If loose type piston pin pads are used, they should be inserted and the cylinder slipped down to the oil ring. Compress the oil ring with the compressor and slide the cylinder over it. The cylinder may now be inserted in the case, taking care that this is done squarely. Do not use any force or prying to make the cylinder skirt enter the case. Slip the cylinder onto the hold-down studs and replace the hold-down nuts. Note: On some engines it is possible to put the cylinder on backwards. Obviously, this should be checked. Tighten the cylinder hold-down nuts evenly, using the correct type of wrench. The safeties should be replaced immediately.

Cylinder Bank - In line or Vee engines, the cylinder bank, crankcase surface and pistons should be prepared in the manner described above before the bank is assembled to the engine. When assembling the bank it is desirable to have it supported by overhead cables, as shown in Fig. II. Before lowering the cylinder bank to the engine, the crankshaft should be rotated so that the pistons furthest from the ends of the crankshaft will enter the bank first. Actually, the cylinder bank is not lowered onto the piston, but is

merely supported while the pistons are forced into the case by the rotation of the crankshaft. In the illustration shown in Fig. II, the two inside pistons have entered the cylinders and the next two pistons, Nos. 2 and 5, are ready to enter. Note that the rings are being compressed while an assistant stands ready to force them into the cylinders by turning the crankshaft. After all the pistons are in place the bank may be lowered carefully onto the case. It is a good plan to rotate the crankshaft back and forth slightly during this operation to prevent any possibility of binding which may be caused by misalignment. After the cylinder bank is in place and the hold-down nuts are snug, the entire bank should be tightened down evenly. Hold-down nut safeties should be replaced immediately.



ASSEMBLING CYLINDER VERTICALLY
Fig. II

Spark Plugs - As soon as the cylinders are in place the spark plugs should be installed, temporarily at least, to prevent any foreign matter from getting into the cylinder. For correct installation of spark plugs, see the chapter on Ignition.

Induction Pipes - Induction pipes should be installed with new packing and new gaskets. If rubber packing is used it must not be shellacked or treated with any other material which acts as a seal. The cylinder intake gasket should be shellacked to the cylinder and coated with a graphite oil paste on the other side. There are several other types of gasket seal preparations which many mechanics prefer to use; however, this is largely a matter of personal preference.

Intake Manifolds - Great care should be taken when installing intake manifolds which are made in a one-piece aluminum alloy casting. The manifold-to-cylinder gasket should be prepared as described above, the manifold slipped in place and the capscrews or nuts tightened evenly. The safeties should be replaced immediately.

Push Rods - The sequence for installing the push rods and push rod housings cannot be listed, as it varies in almost every case, however the following precautions should be taken in any installation:

Make sure that all bearing surfaces are lubricated.
Make sure that the push rods are installed with the correct end up.
If the push rod housing is of the telescoping type, make sure it is snapped into place and that the rubber sleeve covers the joint.
If pressure lubrication is used, all oil lines should be connected immediately.

CHECKING VALVES

Checking the valve clearance is an important operation which has much to do with the smooth running of the engine. This will be understood when it is realized that a few thousandths of an inch variation in the clearance of a valve actually throws that cylinder out of time, and causes a decided reduction in the power output. Inasmuch as checking valves is so important and also a job that must be performed frequently by the mechanic, the various engine manufacturers' instruction books should be studied for exact details.

Valve Adjusting on Individual Cylinders - When speaking in reference to radial engines, the term "checking valves" means more than simply adjusting the valve clearance. At the same time that the clearance is checked the rocker arm and all its accessories should be inspected and lubricated. Fig. I shows the method of checking rocker arm side clearance with a thickness gage. The rocker arm roller should also be inspected for cracks, rust, flat spots, etc. As far as possible the retaining washers and springs should be inspected for rust, breakage and position.

Valves should be adjusted only when the cylinder in question is on top center of the firing stroke. This position may be ascertained as described in Chapter 4. It is customary to check No. 1 cylinder first, and then proceed in the firing order of the engine, or every other cylinder, for by this means it will be necessary to turn the propeller through the interval of only two cylinders, instead of through one complete revolution, as would be necessary in checking the valves on an adjacent cylinder.

Valve clearance is adjusted by placing a feeler gage of the correct thickness between the roller,

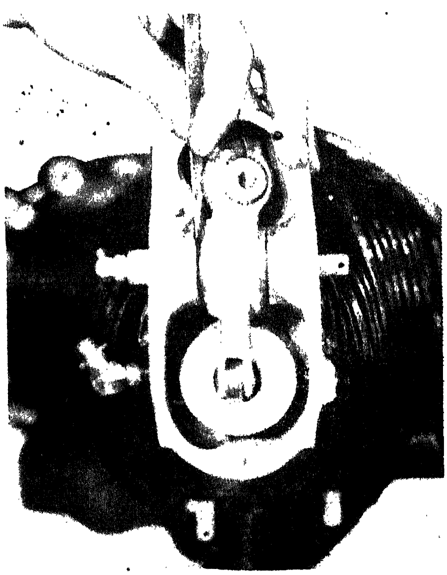
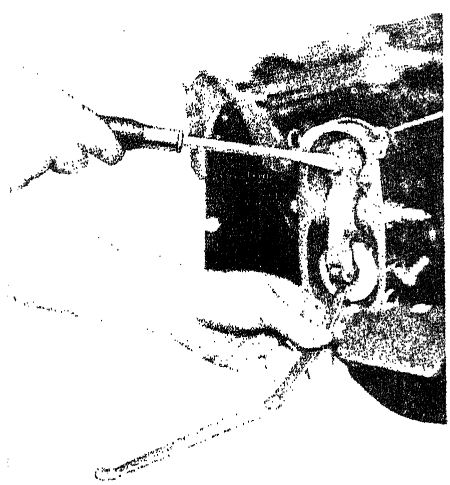


Fig. I



Courtesy Wright Aeronautical Corp.

Fig. II

or tappet, and the valve stem and turning the adjusting screw until the correct clearance is obtained. There are various types of adjusting screws and, of course, the method of turning and safetying each varies. Fig. II illustrates the proper method for adjusting the valve clearance on a Wright Cyclone. After the correct clearance is obtained the adjustment should be locked and the clearance rechecked, as sometimes the adjustment slips while it is being tightened. If the adjustment is not correct, the procedure will have to be repeated.

Adjusting Clearance on Cylinder Banks - After the camshaft has been installed the valve clearance should be set on each individual valve. To do this, turn the camshaft so that the cam lobe is at its highest point, or pointing directly away from the valve or cam follower, as the case may be. Inserting a feeler gage of the proper thickness between the low point on the cam and the valve (or the cam follower), the adjustment can be turned until the correct clearance is obtained. After the clearance has been set and checked the camshaft should be turned through one complete revolution to make sure of its free operation. When the cam is at its lowest point, or when it is depressing the valve to the extreme, inspect the valve to see if it is possible to open it any further. This can be done by placing a small pinch bar or heavy screw driver under the cam lobe in such a manner as to open the valve further. If there is no additional travel left, it is probable that some improper part has been used, that an incorrect adjustment has been made, or that the cam follower is binding in its guide. Obviously, the matter should be investigated.

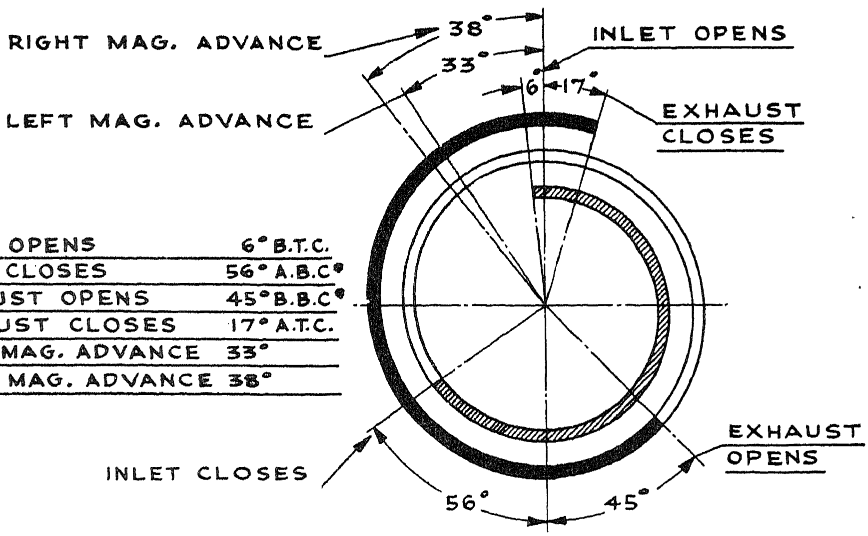
TIMING THE ENGINE

This operation becomes necessary during a top overhaul only in case a camshaft has been removed. The timing of a radial engine or a line engine having an internal camshaft is not disturbed during a top overhaul.

To time the camshaft to the crankshaft, the camshaft drive, or tower shaft, should be replaced so that the timing gear marks on all the gears involved are perfectly aligned. In the majority of cases these timing marks are clearly indicated. If not, more specific directions for timing the camshaft will be found in the engine manufacturer's instruction book. After replacing the tower shaft, the valve timing should be checked in the manner described below.

Checking Valve Timing - To check the valve timing it is desirable to have a top dead center indicator and a timing disc, such as described in Chapter 4. Note: On some engines a timing disc is unnecessary, as the timing marks are indicated on some rotating part, such as the cam ring. This is especially true of the larger types of geared engines. It should be noted here, also, that in a geared engine the propeller shaft rotates at a different speed and in some cases in a different direction from the crankshaft. In addition to the tools required, the timing specifications for the engine will have to be secured. These may usually be found stamped on a plate which is attached to the engine, but if not, they may be found in the engine manufacturer's instruction book, where they are sometimes illustrated as shown in Fig. I. This illustration serves not only to

INLET OPENS	6° B.T.C.
INLET CLOSES	56° A.B.C.
EXHAUST OPENS	45° B.B.C.
EXHAUST CLOSES	17° A.T.C.
LEFT MAG. ADVANCE	33°
RIGHT MAG. ADVANCE	38°



Timing Chart Fig. I

show the opening and closing position of each valve, but also the length of time each valve remains open and closed.

The first step in checking the timing is to ascertain the exact top dead center of the piston in No. 1 cylinder, and set the timing disc to read zero degrees at this point. If No. 1 cylinder is on the compression stroke, both valves will be closed. Note: On most radial engines it is necessary to reset the valves, on the cylinder used for timing, to the "timing clearance." Such an adjustment is required to make allowance for the expansion of the cylinder when it is raised to engine running temperature.

Turning the propeller in the direction of rotation, the first position to be checked will be the opening of the exhaust valve. This is usually in the vicinity of 40° to 60° before bottom center. Turn the propeller to approximately 70° before bottom center, then grasp the exhaust valve retaining washer between the thumb and fingers and attempt to rotate it back and forth. It will be possible to rotate the retaining washer within definite limits; however, if the valve is closed there will be sufficient frictional tension on the face and seat surfaces to prevent the valve itself from rotating. On some of the smaller types it is possible to rotate the retaining washer. This is not to be confused with the rotation of the valve which may be verified by observing the end of the valve stem. To locate the exact position at which the valve opens, a constant pressure should be held on the retaining washer and the propeller moved forward slowly. As soon as the valve starts to open the valve face will be lifted off the seat, leaving the valve free to rotate. A little experience will enable the mechanic to know when the valve is "dragging" on the seat. This indicates that the valve has just started to open, which is the correct position for valve timing. Make a note of the position indicated on the timing disc.

Turning the propeller in the direction of rotation, the next position to be checked will be the opening of the intake valve, which is done in the same manner as described above. This position should also be noted.

The next point to be checked is the closing of the exhaust valve. To determine this point, grasp the retaining washer as described above, and oscillate it continuously while an assistant moves the propeller forward slowly. Again, a little experience will enable the mechanic to feel when the valve starts to drag, which indicates that the valve is about to close. This procedure should be repeated to locate the closing position of the intake valve.

If the readings so obtained vary more than a few degrees from those given by the engine manufacturer, the engine should be retimed. This is a job which should be performed only under the supervision of an experienced mechanic.

ACCESSORIES AND ATTACHMENTS

Rocker Box Covers - Before the rocker box covers are replaced the lubricating pads which are inside should be refreshed or renewed. If no such pad is used, the interior of the cover should be inspected to make sure that it will not come in contact with the rocker arm. The correct fastenings and safeties should be replaced immediately.

Camshaft Covers - Before replacing the camshaft cover the valve mechanism should be generously lubricated and a quantity of lubricating oil poured into the tower shaft housing. In many cases it is advisable to fill all low pockets so that there will be no possibility of a lack of lubrication when the engine first starts. If a soft gasket is used it should be prepared with a suitable sealing compound, as previously described.

Carburetor - If the carburetor was removed it may now be replaced, making sure that all carburetor gaskets and fuel lines are in good condition. When installing the carburetor on a Vee type engine it is particularly important that it be properly aligned between the manifolds on each bank.

Cylinder Attachments - All minor attachments on the cylinder, such as primer lines, thermocouple wires, and air injection starter lines should be connected to the proper fittings. The spark plug wires should be connected to the spark plugs and safetied there.

Exhaust System - The exhaust system should now be assembled to the engine, using copper or asbestos exhaust gaskets. It is not necessary to put any type of sealing compound on these gaskets. Make sure that the exhaust stacks and joints are secure and gas-tight and that the exhaust gases cannot come in contact with any part of the structure.

AFTER OVERHAUL

After an engine has had a top overhaul it should be operated for several hours for the purpose of running in any new parts. An opportunity is afforded at the same time to inspect the engine for any oil leaks, loose accessories, etc. which may accompany a reassembly.

For the first portion of the run-in period, it is desirable to operate the engine without cowling, to facilitate inspection.

The exact procedure to be followed when breaking in a newly overhauled engine varies somewhat with the type and size of engine. In general, the larger engines require a longer run-in period than the smaller types. Special items to be noted during this period will be found in the manufacturer's instruction manual. The following procedure is applicable to most engines.

1. Start the engine in the conventional manner, as described in Chapter 5. Note: Due to the excessive amount of oil in the cylinders it may be necessary to use more priming charge than usual. If the engine fails to start immediately it may be due to the excessive amount of oil having fouled the spark plugs.

2. As soon as the engine starts, check the oil pressure gage to see if the pumps are functioning correctly. If the oil pressure does not come up to the allowable minimum within the first half-minute of engine operation the engine should be stopped immediately. Note: It may be necessary to re-prime the engine oil pump lines before the pump will pick up pressure.

3. The engine should be run slowly (at idling speed) for the first fifteen minutes, after which it should be stopped and a thorough inspection made. All cylinders should be felt to note if any one is running exceptionally hot. Note: It is important that the correct type of oil and gasoline be used, as an incorrect grade of either may lead to excessive heat.

4. After fifteen minutes of running, the engine may be operated at a slightly higher r.p.m. for the next half-hour. The speed of the engine should be increased slightly every thirty minutes, so that at the end of four hours' running it will be operating at approximately one-half its maximum r.p.m. This speed should be continued for the full duration of the run-in period of from 8 to 10 hours, except for occasional accelerations to maximum ground r.p.m. Caution: The engine temperature gages should be watched carefully during this time to make sure that the maximum allowable temperature is not exceeded.

5. After the run-in time has been completed, the power plant should be cleaned thoroughly, inspected, and the cowling replaced.

CHAPTER 17
TROUBLE SHOOTING

When an engine or any part of the power plant installation does not function properly, it is the trouble shooter's job to locate the cause and correct it. This type of work requires not only a thorough understanding of engine principles and a familiarity with a great many types of engines and their "weak spots", but also the ability to think clearly and logically. Only long experience will enable a mechanic to consistently locate engine troubles quickly. Realizing this the apprentice mechanic should take every opportunity to work with an experienced trouble shooter and observe his procedure. In addition to observation the beginner should develop the habit of anticipating engine troubles. For example, when working on any part of an engine the mechanic should become thoroughly familiar with the part and its relationship to the engine. He should ask himself what would happen if this part failed, what would be the logical indication of such a failure and, of course, what precautions he should take to prevent its failure.

It is obviously impossible to outline a definite procedure to follow when locating engine troubles; however, some suggestions may prove to be helpful. The first step is to analyze correctly the problem. It is not sufficient to say that the engine does not run properly, but the trouble must be defined exactly. For example, "the engine fails to develop its full horsepower at high speed", or "cylinder No. 6 does not fire." This may seem elementary but it is one of the most important items in isolating the trouble.

Next, review all of the possible causes which singly or combined could produce the specific trouble. This is not an easy job and is one that is frequently overlooked. Too many mechanics are prone to discount the possibility of two or more things going wrong simultaneously and which, when combined, could produce the effect noted. If possible the engine manufacturer's manual should be consulted. Many times it includes a list of trouble-causing items peculiar to the particular engine and its accessories.

The next logical step is to select the cause that seems the most likely, and investigate. For example, if cylinder No. 6 does not fire it would be natural to suppose that the spark plugs are defective. Investigate this by installing good plugs in the cylinder and then testing to see if the trouble is corrected. If it isn't, at least the elimination of one source has been accomplished. This process of elimination should be continued until the real cause of the trouble has been located and corrected.

A few of the more common engine troubles are listed below. Those for which the correction is not obvious are discussed elsewhere in this book.

FAILURE OF ENGINE TO START

1. Ignition switch off
2. Out of fuel
3. Oily or fouled spark plugs
4. Magneto points stuck open or held apart
5. Wax on magneto points
6. Magneto ground wires broken and grounded
7. Over or under primed
8. Engine too cold
9. Water in the carburetor
10. Wet ignition (spark plugs, magneto, harness)
11. Failure of carburetor control to function properly
12. Incorrect throttle setting
13. Incorrect timing or valve clearance
14. Air leaks in induction system

FAILURE OF ENGINE TO RUN PROPERLY AT IDLING SPEED

1. Idling jet restricted
2. Incorrect idling speed adjustment
3. Throttle valve closing too far
4. Cracked intake manifold
5. Air leak in the induction system
6. Improper valve clearance
7. Engine fouls spark plugs when idling
8. Excessive play in carburetor controls
9. Compensator needle leaking (Chandler-Groves carburetor)

FAILURE OF ENGINE TO DEVELOP FULL POWER

It is customary to check the r.p.m. of an engine at wide open throttle on the ground. A properly functioning engine may have a considerable variation in speed due to atmospheric conditions or to a different propeller pitch setting. If the airplane is faced into the wind the engine r.p.m. will be greater than when the wind is from the side or the rear. This may cause a variation of as much as 100 r.p.m. The above items should be taken into consideration before looking elsewhere for the cause of the trouble.

1. Faulty ignition
   a. Ignition out of time
   b. Weak magneto magnets
   c. Excessively burned or pitted points
   d. Defective spark plugs
2. Incorrect carburetion
   a. Mixture too lean or too rich
   b. Throttle valve not fully open
   c. Improper grade of fuel
   d. Intake manifold too cold
   e. Air leak in carburetor
   f. Incorrect fuel pressure
   g. Turbulent flow of air in intake horn

3. Improper lubrication
   a. Oil too heavy
   b. Oil temperature too low or too high
   c. Overhead not properly lubricated
4. Miscellaneous
   a. Pre-ignition
   b. Incorrect valve timing
   c. Weak springs (valve action slow)
   d. Improper valve clearance
   e. Compression too low
   f. Excessive carbon
   g. Leaking valves
   h. Exhaust manifold constricted (back pressure)
   i. Engine stiff or tight
   j. Incorrect propeller setting

ENGINE STOPS

1. Magnetos grounded
2. Out of fuel
3. Carburetor jets restricted
4. Air or vapor lock in fuel line
5. Fuel lines partially obstructed
6. Structural failure

ENGINE MISSES REGULARLY ON ONE OR MORE CYLINDERS

1. Fouled spark plug
2. Defective spark plug
3. Broken or grounded spark plug wire
4. Improper valve clearance
5. Low compression on one or more cylinders
6. Damaged distributor head

ENGINE MISSES INTERMITTENTLY

1. Incorrect mixture
2. Improper grade of fuel
3. Water in fuel
4. Air leaks in induction system
5. Slow valve action
6. Defective magnetos
7. Distributor points or contacts dirty

IMPROPER ACCELERATION

1. Improper idling adjustment
2. Defective accelerating pump
3. Pump lock plunger stuck in OFF position (Chandler-Groves Carb.)

IMPROPER FUEL PRESSURE

1. Air leak in system
2. Improperly adjusted relief valve
3. Clogged strainers
4. Vapor lock
5. Leaky float
6. Damaged needle valve
7. Excessive fuel supply pressure
8. Improper float level
9. Worn fulcrum pin

IMPROPER OIL PRESSURE

1. Air leak in system
2. Improperly adjusted relief valve
3. Clogged strainers
4. Improper grade of oil
5. Vapor lock
6. Excessive bearing clearance
7. Oil too hot
8. Atmospheric temperature too low
9. Lack of priming
10. Oil foaming in supply tank

ENGINE VIBRATES EXCESSIVELY

1. Propeller out of balance or out of track
2. Bent crankshaft
3. Unequal valve clearance
4. Defective spark plugs
5. Engine loose on mount
6. Propeller hub nut loose
7. Improper hot air distribution
8. Ice formation in carburetor
9. Incorrect carburetor setting
10. Engine too cold

EXCESSIVE FUEL CONSUMPTION

1. Mixture too rich
2. Jets too large
3. Ignition timing late
4. Engine running too cold
5. Worn piston rings
6. Leaking valves

EXCESSIVE OIL CONSUMPTION

1. Improper grade of oil
2. Worn piston rings
3. Worn main bearing
4. Crankcase compression
5. Overheating

ENGINE WON'T STOP WHEN SWITCH IS TURNED OFF

1. Magneto ground wires broken
2. Engine excessively hot
3. Excessive carbon

OIL TEMPERATURE TOO HIGH

1. Improper grade of oil
2. Oil that has been run too long
3. Insufficient oil coolers
4. Ignition too late
5. Pre-ignition
6. Improper engine cooling
7. Improper grade of fuel
8. Not enough oil
9. Dirty oil
10. Scavenger oil pump not cleaning crankcase
11. Worn piston rings
12. Piston rings installed upside down
13. Improper venting
14. Incorrect air baffling

CHAPTER 18
FUEL AND OIL

Fuel is a substance which when properly mixed with air, produces heat through combustion. For the present types of internal combustion engines, the fuel is invariably in liquid form and, except in the case of Diesel engines, nearly always consists of gasoline, either pure or combined with relatively small amounts of other fuels or chemicals, such as benzol or tetraethyl lead, to improve its anti-knock properties.

Gasoline, commonly referred to by mechanics as "gas", and lubricating oils are derived usually from the same source - crude petroleum. Crude petroleum is a mixture of numerous hydrocarbons and natural impurities. Its general composition varies widely with the different localities in which it is found. In the United States the various crudes are commonly classified geographically into four main groups:

1. Pennsylvania Crudes
2. Gulf Coast Crudes
3. California Crudes
4. Mid-continent Crudes

They may also be classified with respect to the hydrocarbons which predominate in their composition, as:

1. Paraffin Base Crudes
2. Asphalt Base Crudes
3. Naphthene Base Crudes
4. Mixed Base Crudes

Although there is no sharp dividing line, in general, the numbers of the two types of classifications coincide; that is, the Pennsylvania crudes are of paraffin base, the Gulf Coast of asphalt base, etc.

Paraffin base crudes are commonly given the preference for the production of lubricating oils, and naphthene base crudes for aviation gasoline.

REFINING PROCESSES

Crude petroleum is transported from the oil fields by tank cars or pipe lines and stored in tanks at the refinery. Moisture and sediment are allowed to settle to the bottom and are drawn off. The crude oil is then ready for refining by distillation.

This process utilizes the fact that the many compounds of which petroleum is composed have different boiling points. In other words, they evaporate or vaporize at different temperatures. For example, gasoline vaporizes at a relatively low temperature, kerosene at a higher, and lubricating oil requires still more heat. Thus, by heating the crude oil, the lighter and more volatile elements such as

gasoline will be vaporized first, and the heavier portions last. The vapors are condensed as they rise in the still, and led off to their respective tanks. This type of refining process is known as "fractionation."

A modern refining plant is a rather complicated series of stills, condensers, filters and tanks, but the principles involved are fairly simple. The two important units are a furnace for converting the crude petroleum into crude vapor, and a fractionation tower where the vapors cool and settle in different sections according to their volatility. Inside of the tower is a series of "bubble trays." The rising vapors are forced to pass through bubble caps in each tray and in doing so, bubble through the liquid accumulated in the tray. A diagram of the bubble trays is shown in Fig. 1. In passing through the liquid in this manner, the vapors are stripped of any entrained liquid and the heavier vapors are condensed. The more volatile portions pass up to the next higher, and cooler, tray. The liquid flows through the pipes p, to the next lower and hotter tray. Thus a continuous re-distillation takes place and accurate fractionation obtained. The vapors are led from the fractionating tower at various points to condensers and purifying units, and thence to storage tanks.

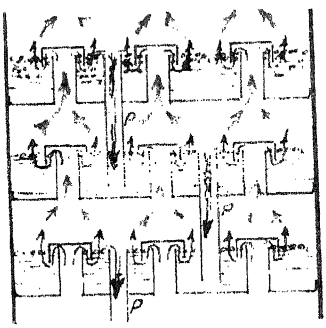


FIG. I

It should be borne in mind that the preceding description is greatly simplified and by no means covers the entire details of the process.

TYPES AND REQUIREMENTS OF GASOLINE

There are three main types of gasoline, classified according to the method of manufacture. As a rule, two or more of these types are blended before the product is put on the market.

Straight Run Gasoline- This type of gasoline is obtained by the fractionation process previously described. This process makes it possible to separate the light and highly volatile gasoline from that which is less volatile. After separation, the light and heavy are blended in varying percentages to produce fuels which will meet certain requirements and specifications.

Approximately 65% of all gasoline used is of the straight-run type. It is considered the most satisfactory for aviation and other internal combustion engines.

Cracked Gasoline- There is, of course, a limit to the amount of gasoline which can be produced from a given quantity of crude petroleum by fractionation. In order to obtain more, the "cracking" process was developed.

This process consists in general, of subjecting some of the

heavier products of distillation to high temperature and high pressure at the same time, thus "cracking" the heavier molecules into lighter and more volatile fractions. The oil most commonly used in this process is Gas Oil, which is the next heavier distillate after kerosene.

Cracked gasolines contain a comparatively high amount of unsaturated hydrocarbons which have a tendency to oxidize and form gums during storage. These elements must be removed by chemical treatment. On the other hand, gasoline of this type has better anti-knock properties than straight-run, and hence are frequently blended with the latter to obtain fuel of satisfactory low knocking quality.

Natural Gasoline - Gasoline which is made or extracted from natural gas is called "natural" gasoline: It is obtained by the compression of rich gases which come from oil wells, or by the absorption of lean gases from the same source.

In the compression method, the gas is compressed, which causes a rise in temperature. The hot vapor is then cooled, which causes it to condense into a liquid. In the absorption method, the gas is forced into a refined petroleum oil which contains no gasoline. The gas is absorbed by the oil, which is then distilled by the use of steam.

Natural gasoline is very light or volatile and is used for blending with heavier types to improve their properties with respect to starting the engine.

REQUIREMENTS OF AVIATION GASOLINE

There are three main considerations involved in the testing of gasoline: volatility, purity, and knock rating.

Volatility - Volatility is measured by a distillation test. A glass flask equipped with a tube for leading off the vapor and a thermometer, the bulk of which is above the level of the liquid, is used for this test. In the standard procedure, 100 c.c. of the gasoline is put in the flask, which is then heated at a specified uniform rate. The tube which leads off the vapors passes through a box of ice, so that the vapors are condensed and fall into a container. The heat is so regulated that the first drop falls from the tube within five to ten minutes. The temperature at this time is called the initial boiling point. The heat is then regulated so that four to five c.c. of the gasoline are condensed every minute until 90% has been distilled. It is then increased so that the end point is reached within five minutes. The end point is the maximum temperature indicated by the thermometer during the test, and when it has been reached, the temperature will begin to drop. The source of heat is removed and the bottom of the flask will be found to be dry or with perhaps a small residue remaining.

If the gasoline has good properties with respect to starting the engine, about 10% should be distilled at a temperature of about 149° F. For proper vaporization and distribution, 90% should be distilled at approximately 284° F. The temperature at which 50% has

been distilled should be the average between the 10% and 90% temperatures just mentioned. The residue should be not more than 2%.

While high volatility is desirable for easy starting, good distribution, low crankcase dilution, and high octane rating, it must not vaporize so easily as to "boil" in the fuel lines. This condition may cause a "vapor lock" with consequent engine failure. An initial boiling point below 95° F. or a distillation loss of more than 3% is likely to indicate danger in this respect.

Purity - Gasoline is usually tested for corrosive properties, for gum content, for acidity, and for sulphur content.

The corrosion and gum tests are made at the same time, by pouring the gasoline into a highly polished copper dish and evaporating the liquid completely in a steam bath. There must be no evidence of black or gray corrosion on the dish and the amount of gum must be less than 3 milligrams per 100 c.c. of gasoline.

The acidity is tested by using the residue from the distillation test, mixed with three times as much distilled water and thoroughly shaken up. The aqueous layer is removed and tested with one drop of methyl orange. No pink or red color should show.

The sulphur test is conducted by burning the fuel, collecting the products of combustion and passing them through a solution of sodium carbonate. The decrease in the alkalinity of the solution indicates the amount of sulphur in the gasoline. The sulphur content should not exceed 0.10%, since sulphur tends to form sludge in the crankcase and to cause corrosion of bearing surfaces.

Antiknock Rating - This quality is commonly referred to as "octane rating." The basic method of determining octane rating has been previously discussed in Chapter 1. The octane rating required varies with the engine in which the fuel is to be used, whereas the specifications with respect to volatility and purity are more definite for all aircraft engines.

REQUIREMENTS AND SPECIFICATIONS FOR LUBRICATING OIL

Among the heavier products of fractionation are lubricating distillate and cylinder stock. These two are further refined and mixed in varying proportions to obtain the desired characteristics of gravity, viscosity, flash point, etc., discussed below.

Gravity - The gravity of liquid petroleum products is measured by means of the A.P.I. (American Petroleum Institute) hydrometer, which has superseded the Baume hydrometer formerly used. This instrument is the same in general design as the hydrometer used for testing batteries, described in the chapter devoted to Ignition. The scale, however, is different. The A.P.I. gravity of water is 10°. Oil and other liquids which are lighter than water give higher values, heavier liquids give lower values. In the back of this book will be found a conversion table giving the specific gravity and weight per gallon corresponding to various A.P.I. gravities.

Flash and Fire Point - The flash point of oil is the lowest tem-

perature at which the vapors produced by heating a sample will ignite without setting fire to the oil itself. The rate of heating must not be greater than 30° F. per minute at first, and must be between 11° F. and 9° F. per minute for the last 50° F. before the flash point is reached. The oil is heated in an open cup, the temperature of the liquid being indicated continuously by a thermometer. When the vapor can be ignited by passing a small flame over the cup, the temperature is noted. This is the flash point. It varies with the grade but normally lies between 425° F. and 500° F. The fire point is the lowest temperature at which the oil itself will ignite from the burning vapor.

Viscosity - The viscosity of an oil is one of the characteristics which determine how readily it will flow or circulate. The instrument used to measure viscosity is the Saybolt Universal Viscosimeter. With this device, the determinations are made at either 100° F. or 210° F.

The oil is heated in a bath similar to a double boiler, the bottom of the inner container which carries the oil being provided with an outlet tube of a definite size. When the oil has reached the proper temperature, the tube is opened and the oil allowed to drain into a graduated receptacle. By means of a stop watch, the number of seconds required for 60 c.c. of oil to flow into the receptacle is measured. This number is the Saybolt Viscosity Number, and is ordinarily used to indicate the grade when the test has been made at 210° F. in the case of aviation oil. Thus, an oil of Grade 77 would fill a 60 c.c. container in 77 seconds if heated to 210° F. The grades of aviation engine oils usually run from 77 to 140, depending on the climate and the type of engine. Hot weather, or engines which run at high temperatures, call for a higher number.

S.A.E. Viscosity numbers are sometimes used instead of the Saybolt. A table showing the S.A.E. numbers with the corresponding Saybolt numbers will be found with the other tables in the back of this book.

Pour-point - The pour-point of oil is the lowest temperature at which it will flow without being stirred or otherwise disturbed. The pour-point is an indication of the suitability of oil for cold weather use. The test is conducted by placing a small jar, containing the oil to be tested, in some sort of refrigerator or cooling medium. As the temperature of the oil, checked by a thermometer, is lowered, an effort is made to pour it at each five-degree drop. The highest temperature at which the oil shows no movement when the jar is held horizontal for five seconds is the pour-point.

The pour-point of oil naturally varies with the grade. For Grade 77, it is 0° F. and for Grade 140, 30° F.

Carbonization - If oil leaves a heavy carbon deposit when burned, it is obviously not suitable for use in internal combustion engines.

The carbonizing tendency may be determined to some extent by allowing drops of oil to fall on an inclined steel rod, the lower

end of which is heated by a Bunsen burner. As the oil runs down the hot rod, the effect of different temperatures may be observed. It should be noted that this test is useful chiefly for comparative purposes.

General - The oil must be free from acid, and should be reasonably transparent in a layer about one inch thick. It should maintain its viscosity under heat, so that the viscosity when cold need not be so high as to prevent proper circulation.

It has been found that good oil never "wears out", and hence becomes unfit for use only when diluted with unburned fuel or when it carries carbon, dirt or water in suspension. It may then be reclaimed by a process of filtering and redistillation. After this treatment it is not only as safe to use as new oil, but is considered by many to be superior.

CHAPTER 19

TABLES

The following tables, formulas and charts are presented here so that they may serve as ready reference material for the aircraft engine mechanic.

MEASURE OF LENGTH -

English

1 Mile = 1760 yards = 5280 feet
1 Yard = 3 feet = 36 inches
1 Foot = 12 inches
1 Mil = .001 inch
1 Fathom = 2 yards = 6 feet
1 Rod = 5.5 yards = 16.5 feet
1 Hand = 4 inches
1 Span = 9 inches

Nautical Measure

1 League = 3 nautical miles
1 Nautical Mile (Knot) = 6080.26 feet = 1.1516 statute mile
One degree at the equator = 60 nautical miles
360 degrees = 21,600 knots = 24,874.5 statute miles

Metric

1 Millimeter (mm.) = 0.03937079 inch, or about 1/25th inch
10 Millimeters = 1 Centimeter (cm.) = 0.3937079 inch
10 Centimeters = 1 Decimeter (dm.) = 3.937079 inches
10 Decimeters = 1 Meter (m.) = 39.37079", 3.280', or 1.0936 yds.
10 Meters = 1 Decameter (Dm.) = 32.808992 feet
10 Decameters = 1 Hectometer (Hm.) = 19.927817 rods
10 Hectometers = 1 Kilometer (Km.) = 1093.61 yds. or .62138 mile
10 Kilometers = 1 Myriameter (Mm.) = 6.213824 miles
1 Inch = 2.54 cm., 1 foot = .3048 m., 1 yard = .9144 m., 1 rod= .5029 Dm., 1 mile = 1.6093 Km.

MEASURE OF WEIGHT

Avoirdupois

1 Ounce = 16 drams = 437.5 grains
1 Pound = 16 ounces = 7000 grains
1 Ton = 2000 pounds
1 Long Ton = 2240 pounds

Metric

1 Gramme (g.) = .03527398 oz. avoir.
10 Grammes = 1 Decagramme (Dg.) = .3527398 oz. avoir.
10 Decagrammes = 1 Hectogramme (Hg.) = 3.527398 oz. avoir.
10 Hectogrammes = 1 Kilogramme (Kg.) = 2.20462125 lbs.
1000 Kilogrammes = 1 Tonne (T.) = 2204.62125 lbs., or 1.1023 tons of 2000 lbs.
1 Grain = 0.0648 g., 1 oz. avoir = 28.35 g., 1 lb. = .4536 Kg., 1 ton 2000 lbs. = 0.9072 T.

MEASURE OF CAPACITY

English

1 Liquid ounce = 8 Drams
1 Pint = 16 Ounces or 4 Gills
1 Quart = 2 Pints
1 Gallon = 4 Quarts
1 Gallon = 231 Cu. In.
1 Cubic Foot = 7.4805 Gallons

Metric

1 Liter (l.) = 1 cubic decimeter = 61.0270515 cu.in. or .03531 cu.ft., or 1.0567 liquid qts., or .26417 Amer. gal.
10 Liters = 1 Decaliter (Dl.) = 2.6417 gallons
10 Decaliters = 1 Hectoliter (Hl.) = 2.8375 bu.
10 Hectoliters = 1 Kiloliter (Kl.) = 61027.0515 cu.in.
1 Cu.ft. = 28.317 l., 1 Amer. gal. = 3.785 l.

AREAS

Squares

144 Sq. Inches = 1 Square foot
9 Sq. Ft. = 1 Sq. Yard
43,560 Sq. Ft. = 1 Acre
640 Acres = 1 Sq. Mile
The area of a square = A side multiplied by a side
A side x 1.4142 = diameter of its circumscribing circle
A side x 4.443 = circumference of its circumscribing circle
A side x 1.128 = diameter of an equal circle
A side x 3.547 = circumference of an equal circle
Square inches x 1.273 = circle inches of an equal circle

Circles and Spheres

The area of a circle = 3.1416 x radius squared
= .7854 x diameter squared
= .07958 x circumference squared
= circumference x 1/4 diameter
1 Circular inch = .7854 sq. in.
The area of a sphere = 3.1416 x Diameter squared

OTHER INFORMATION PERTAINING TO CIRCLES

Circumference = 3.1416 x Diameter
Circumference = 6.283185 x Radius
Diameter = .31831 x Circumference
Radius = 1/2 Diameter
Radius = .159155 x Circumference
Radius = .56419 x Square root of area
To find the diameter of a circle equal in area to a given square, multiply a side of the square by 1.12838
To find the side of a square equal in area to a given circle, multiply the diameter by .8862

VOLUMES

The volume of a cube = Length x Width x Height
The volume of a sphere = .5236 x Diameter cubed
1 Cubic foot = 1728 cubic inches
1 Board foot = 144 Cubic inches

WEIGHTS OF SUBSTANCES

Liquids

Water per gallon = 8.336 lbs. (at 39° F.)
Oil per gallon = approximately 7.5 lbs.
Gasoline per gallon = approximately 6 lbs.

Solids (Per sq. ft., 1/8 in. thick)	Approximately
Aluminum (2-SO) =	1.81 lbs.
Balsa =	.073 lbs.
Chrome Molybdenum Steel =	5.222 lbs.
Cork =	.104 lbs.
Duralumin (17 ST) =	1.80 lbs.
Lead =	7.40 lbs.
Mild Carbon Steel =	5.166 lbs.
Plywood (Birch) =	.416 lbs.
Pyralin =	.90 lbs.
Spruce (Per board foot) =	2.25 lbs.

CHART FOR SELECTING WRENCH OPENINGS

Wrench Opening in Inches	S.A.E. Bolts & Nuts	Amer. Std. Nuts	Amer. Std. Bolts
5/32	.....	0 & 1	.....
3/16	.....	2 & 3	.....
1/4	.....	4	.....
5/16	.....	5 & 6	.....
11/32	.....	8	.....
3/8	.....	10	.....
7/16	1/4	12 & 1/4	1/4
1/2	5/16	.....	5/16
9/16	3/8	5/16	3/8
5/8	7/16	3/8	7/16
3/4	1/2	7/16	1/2
13/16	.....	1/2	9/16
7/8	9/16	9/16	5/8
15/16	5/8	5/8	.....
1"	11/16	.....	3/4
1-1/16	3/4	.....	.....
1-1/8	.....	3/4	7/8
1-1/4	7/8	.....	.....
1-5/16	.....	7/8	1"
1-7/16	1"	.....	.....
1-1/2	.....	1"	1-1/8
1-5/8	1-1/8	.....	.....
1-11/16	.....	1-1/8	1-1/4
1-13/16	1-1/4	.....	.....
1-7/8	.....	1-1/4	.....
2"	1-3/8	.....	.....

CONVERSION TABLES

Degrees Fahrenheit to Degrees Centigrade

F	C	F	C	F	C	F	C	F	C
-40	-40.00	+30	- 1.11	80	26.67	250	121.11	500	260.11
-30	-34.44	35	+ 1.67	85	29.44	275	135.00	525	273.89
-20	-28.89	40	+ 4.44	90	32.22	300	148.89	550	287.78
-10	-23.33	45	7.22	95	35.00	325	162.78	575	301.67
0	-17.78	50	10.00	100	37.78	350	176.67	600	315.56
+ 5	-15.00	55	12.78	125	51.67	375	190.55	650	343.33
+10	-12.22	60	15.56	150	65.56	400	204.44	700	371.11
+15	- 9.44	65	18.33	175	79.44	425	218.33	750	398.89
+20	- 6.67	70	21.11	200	93.33	450	232.22	800	426.67
+25	- 3.89	75	23.89	225	107.22	475	246.11	850	454.44
Centigrade = 5/9 (F.-32)				Fahrenheit = 9/5 C. + 32					

Metric Conversion Table

Millimeters................	x	.03937	=	Inches
Inches.....................	x	25.400	=	Millimeters
Meters.....................	x	3.2809	=	Feet
Feet.......................	x	.3048	=	Meters
Kilometers.................	x	.621377	=	Miles
Miles......................	x	1.6093	=	Kilometers
Square centimeters.........	x	.15500	=	Square inches
Square inches..............	x	6.4515	=	Square centimeters
Square meters..............	x	10.76410	=	Square feet
Square feet................	x	.09290	=	Square meters
Square kilometers..........	x	247.1098	=	Acres
Acres......................	x	.00405	=	Square kilometers
Cubic centimeters..........	x	.061025	=	Cubic inches
Cubic inches...............	x	16.3866	=	Cubic centimeters
Cubic meters...............	x	35.3156	=	Cubic feet
Cubic feet.................	x	.02832	=	Cubic meters
Cubic meters...............	x	1.308	=	Cubic yards
Cubic yards................	x	.765	=	Cubic meters
Liters.....................	x	61.023	=	Cubic inches
Cubic inches...............	x	.01639	=	Liters
Liters.....................	x	.26418	=	U. S. gallons
U. S. Gallons..............	x	3.7854	=	Liters
Grams......................	x	.03527	=	Oz. avoirdupois
Ounces avoirdupois.........	x	28.3495	=	Grams
Kilograms..................	x	2.2046	=	Pounds
Pounds.....................	x	.4536	=	Kilograms
Kilog's per sq. centimeter.	x	14.2231	=	Lbs.per sq. in.
Lbs. per sq. in............	x	.0703	=	Kilog's per sq. cm.
Metric tons (1,000 kilog's)	x	1.1023	=	Tons (2,000 lbs.)
Tons (2,000 lbs.)..........	x	.9072	=	Metric tons
Kilowatts..................	x	1.3405	=	Horsepower
Horsepower.................	x	.746	=	Kilowatts
Calories...................	x	3.9683	=	B. T. units
B. T. Units................	x	.2520	=	Calories

Decimal and Millimeter Equivalents
of Fractional Parts of an Inch

Inches	Inches	mm	Inches	Inches	mm
1/64	.01563	.397	33/64	.51563	13.097
1/32	.03125	.794	17/32	.53125	13.494
3/64	.04688	1.191	35/64	.54688	13.890
1/16	.0625	1.587	9/16	.5625	14.287
5/64	.07813	1.984	37/64	.57813	14.684
3/32	.09375	2.381	19/32	.59375	15.081
7/64	.10938	2.778	39/64	.60938	15.478
1/8	.125	3.175	5/8	.625	15.875
9/64	.14063	3.572	41/64	.64063	16.272
5/32	.15625	3.969	21/32	.65625	16.669
11/64	.17188	4.366	43/64	.67188	17.065
3/16	.1875	4.762	11/16	.6875	17.462
13/64	.20313	5.159	45/64	.70313	17.859
7/32	.21875	5.556	23/32	.71875	18.256
15/64	.23438	5.953	47/64	.73438	18.653
1/4	.25	6.350	3/4	.75	19.050
17/64	.26563	6.747	49/64	.76563	19.447
9/32	.28125	7.144	25/32	.78125	19.844
19/64	.29688	7.541	51/64	.79688	20.240
5/16	.3125	7.937	13/16	.8125	20.637
21/64	.32813	8.334	53/64	.82813	21.034
11/32	.34375	8.731	27/32	.84375	21.431
23/64	.35938	9.128	55/64	.85938	21.828
3/8	.375	9.525	7/8	.875	22.225
25/64	.39063	9.922	57/64	.89063	22.622
13/32	.40625	10.319	29/32	.90625	23.019
27/64	.42188	10.716	59/64	.92188	23.415
7/16	.4375	11.113	15/16	.9375	23.812
29/64	.45313	11.509	61/64	.95313	24.209
15/32	.46875	11.906	31/32	.96875	24.606
31/64	.48438	12.303	63/64	.98438	25.003
1/2	.5	12.700	1	1.00000	25.400

Decimal Inch Equivalents of
Millimeters and Fractions of Millimeters

mm	Inch	mm	Inch	mm	Inch	mm	Inch
1/100 =	.00039	33/100 =	.01299	64/100 =	.02520	95/100 =	.03740
2/100	.00079	34/100	.01339	65/100	.02559	96/100	.03780
3/100	.00118	35/100	.01378	66/100	.02598	97/100	.03819
4/100	.00157	36/100	.01417	67/100	.02638	98/100	.03858
5/100	.00197	37/100	.01457	68/100	.02677	99/100	.03898
6/100	.00236	38/100	.01496	69/100	.02717	1	.03937
7/100	.00276	39/100	.01535	70/100	.02756	2	.07874
8/100	.00315	40/100	.01575	71/100	.02795	3	.11811
9/100	.00354	41/100	.01614	72/100	.02835	4	.15748
10/100	.00394	42/100	.01654	73/100	.02874	5	.19685
11/100	.00433	43/100	.01693	74/100	.02913	6	.23622
12/100	.00472	44/100	.01732	75/100	.02953	7	.27559
13/100	.00512	45/100	.01772	76/100	.02992	8	.31496
14/100	.00551	46/100	.01811	77/100	.03032	9	.35433
15/100	.00591	47/100	.01850	78/100	.03071	10	.39370
16/100	.00630	48/100	.01890	79/100	.03110	11	.43307
17/100	.00669	49/100	.01929	80/100	.03150	12	.47244
18/100	.00709	50/100	.01969	81/100	.03189	13	.51181
19/100	.00748	51/100	.02008	82/100	.03228	14	.55118
20/100	.00787	52/100	.02047	83/100	.03268	15	.59055
21/100	.00827	53/100	.02087	84/100	.03307	16	.62992
22/100	.00866	54/100	.02116	85/100	.03346	17	.66929
23/100	.00906	55/100	.02165	86/100	.03386	18	.70866
24/100	.00945	56/100	.02205	87/100	.03425	19	.74803
25/100	.00984	57/100	.02244	88/100	.03465	20	.78740
26/100	.01024	58/100	.02283	89/100	.03504	21	.82677
27/100	.01063	59/100	.02323	90/100	.03543	22	.86614
28/100	.01102	60/100	.02362	91/100	.03583	23	.90551
29/100	.01142	61/100	.02402	92/100	.03622	24	.94488
30/100	.01181	62/100	.02441	93/100	.03661	25	.98425
31/100	.01220	63/100	.02480	94/100	.03701	26	1.02362
32/100	.01260						

Letter Sizes of Drills

Diameter Inches	Decimals of 1 In.	Diameter Inches	Decimals of 1 In.
A 15/64	.234	N	.302
B	.238	O 5/16	.316
C	.242	P 21/64	.323
D	.246	Q	.332
E 1/4	.250	R 11/32	.339
F	.257	S	.348
G	.261	T 23/64	.358
H 17/64	.266	U	.368
I	.272	V 3/8	.377
J	.277	W 25/64	.386
K 9/32	.281	X	.397
L	.290	Y 13/32	.404
M 19/64	.295	Z	.413

Decimal Equivalent of the Numbers of Twist Drill and Steel Wire Gage

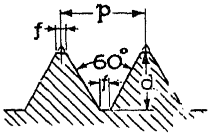
No.	Size of No. in Decimals	No.	Size of No. in Decimals	No.	Size of No. in Decimals	No.	Size of No. in Decimals	No.	Size of No. in Decimals
1	.2280	17	.1730	33	.1130	49	.0730	65	.0350
2	.2210	18	.1695	34	.1110	50	.0700	66	.0330
3	.2130	19	.1660	35	.1100	51	.0670	67	.0320
4	.2090	20	.1610	36	.1065	52	.0635	68	.0310
5	.2055	21	.1590	37	.1040	53	.0595	69	.0292
6	.2040	22	.1570	38	.1015	54	.0550	70	.0280
7	.2010	23	.1540	39	.0995	55	.0520	71	.0260
8	.1990	24	.1520	40	.0980	56	.0465	72	.0250
9	.1960	25	.1495	41	.0960	57	.0430	73	.0240
10	.1935	26	.1470	42	.0935	58	.0420	74	.0225
11	.1910	27	.1440	43	.0890	59	.0410	75	.0210
12	.1890	28	.1405	44	.0860	60	.0400	76	.0200
13	.1850	29	.1360	45	.0820	61	.0390	77	.0180
14	.1820	30	.1285	46	.0810	62	.0380	78	.0160
15	.1800	31	.1200	47	.0785	63	.0370	79	.0145
16	.1770	32	.1160	48	.0760	64	.0360	80	.0135

Different Standards for Wire Gages in use in the United States

Dimensions of Sizes in Decimal Parts of an Inch

Number of Wire Gage	American, or Brown & Sharpe	Birmingham, or Stubs' Iron Wire	Washburn & Moen, Worcester, Mass.	W.& M. Steel Music Wire	New American S & W Co.'s Music Wire Gage	Imperial Wire Gage	Stubs' Steel Wire	U.S. Standard Gage for Sheet and Plate Iron and Steel
0000	.460	.454	.394	.011	.006	.400		.406
000	.409	.425	.362	.012	.007	.372		.375
00	.365	.380	.331	.013	.008	.348		.344
0	.325	.340	.306	.014	.009	.324		.312
1	.290	.300	.283	.015	.010	.300	.227	.281
2	.257	.284	.262	.017	.011	.276	.219	.266
3	.229	.259	.244	.017	.012	.252	.212	.250
4	.204	.238	.225	.018	.013	.232	.207	.234
5	.182	.220	.207	.020	.014	.212	.204	.218
6	.162	.203	.192	.021	.016	.192	.201	.203
7	.144	.180	.177	.023	.018	.176	.199	.187
8	.128	.165	.162	.024	.020	.160	.197	.172
9	.114	.148	.148	.025	.022	.144	.194	.156
10	.101	.134	.135	.027	.024	.128	.191	.041
11	.090	.120	.120	.028	.026	.116	.118	.125
12	.080	.109	.105	.029	.029	.104	.185	.109
13	.071	.095	.091	.031	.031	.092	.182	.093
14	.064	.083	.080	.032	.033	.080	.180	.078
15	.057	.072	.072	.034	.035	.072	.178	.070
16	.050	.065	.062	.036	.037	.064	.175	.062
17	.045	.058	.054	.037	.039	.056	.172	.056
18	.040	.049	.047	.039	.041	.048	.168	.050
19	.035	.042	.041	.041	.043	.040	.164	.044
20	.032	.035	.034	.043	.045	.036	.161	.037
21	.028	.032	.031	.046	.047	.032	.157	.034
22	.025	.028	.028	.048	.049	.028	.155	.031
23	.022	.025	.026	.051	.051	.024	.153	.028
24	.020	.022	.023	.055	.055	.022	.051	.025
25	.017	.020	.020	.058	.059	.020	.148	.021
26	.015	.018	.018	.062	.063	.018	.146	.018
27	.014	.016	.017	.065	.067	.016	.143	.017
28	.012	.014	.016	.072	.071	.014	.139	.015
29	.011	.013	.015	.076	.075	.013	.134	.014
30	.010	.012	.014	.080	.080	.012	.127	.012

American National Coarse and Fine Thread Dimensions and Tap Drill Sizes



p = pitch = $\frac{1}{\text{No. of threads per in.}}$

n = Number of threads per inch

d = depth = pitch x .649519 or $\frac{.649519}{n}$

f = flat = Pitch

Nomina Size	Outside Diameter Inches	Pitch Diameter Inches	Root Diameter Inches	Tap Dril	Decimal Equivalent of Tap Drill
*0-80	.0600	.0519	.0438	3/64	.0469
*1-64	.0730	.0629	.0527	53	.0595
72	.0730	.0640	.0550	53	.0595
*2-56	.0860	.0744	.0628	50	.0700
64	.0860	.0759	.0657	50	.0700
*3-48	.0990	.0355	.0719	47	.0785
56	.0990	.0874	.0758	45	.0820
*4-40	.1120	.0958	.0795	43	.0890
48	.1120	.0985	.0849	42	.0935
*5-40	.1250	.1088	.0925	38	.1015
44	.1250	.1102	.0955	37	.1040
*6-32	.1380	.1177	.0974	36	.1065
40	.1380	.1218	.1055	33	.1130
*8-32	.1640	.1437	.1234	29	.1360
36	.1640	.1460	.1279	29	.1360
*10-24	.1900	.1629	.1359	25	.1495
32	.1900	.1697	.1494	21	.1590
*12-24	.2160	.1889	.1619	16	.1770
28	.2160	.1928	.1696	14	.1820
1/4-20	.2500	.2175	.1850	7	.2010
28	.2500	.2268	.2036	3	.2130
5/16-18	.3125	.2764	.2403	F	.2570
24	.3125	.2854	.2584	I	.2720
3/8-16	.3750	.3344	.2938	5/16	.3125
24	.3750	.3479	.3209	Q	.3320
7/16-14	.4375	.3911	.3447	U	.3680
20	.4375	.4050	.3726	25/64	.3906
1/2-13	.5000	.4501	.4001	27/64	.4219
20	.5000	.4675	.4351	29/64	.4531
9/16-12	.5625	.5084	.4542	31/64	.4844
18	.5625	.5264	.4903	33/64	.5156
5/8-11	.6250	.5660	.5069	17/32	.5312
18	.6250	.5889	.5528	37/64	.5781
3/4-10	.7500	.6850	.6201	21/32	.6562
16	.7500	.7094	.6688	11/16	.6875
7/8- 9	.8750	.8029	.7307	49/64	.7656
14	.8750	.8286	.7822	13/16	.8125
1- 8	.0000	.9188	.8376	7/8	.8750
14	1.0000	.9536	.9072	15/16	.9375

American National Standard Wood Screw Body Diameter Si

Crankcase Lubricating-Oil Viscosity Numbers

S.A.E. Viscosity Number	Viscosity Range Saybolt Universal, Sec.			
	At 130 Deg. Fahr.		At 210 Deg. Fahr.	
	Min.	Max.	Min.	Max.
10	90	Less than 120	...	....
20	120	" " 185	...	....
30	185	" " 255	...	....
40	255	....	...	Less than 75
50	...	....	75	" " 105
60	...	....	105	" " 125
70	...	....	125	" " 150

Gravity and Weight per Gallon Equivalents

A.P.I. Gravity	Specific Gravity $\frac{60^\circ}{60^\circ}$ F.	Pounds Per Gal.
10	1.000	8.328
15	.9659	8.044
20	.9340	7.778
25	.9042	7.529
30	.8762	7.296
35	.8498	7.076
40	.8251	6.870
45	.8017	6.675
50	.7796	6.490
55	.7587	6.316
60	.7389	6.151
65	.7201	5.994
70	.7022	5.845
75	.6852	5.703

CHAPTER 20

ENGINE SPECIFICATIONS

The following information is presented to provide a quick and easy reference to comparative engine specifications. The material found in this chapter has been furnished by the various engine manufacturers listed below, and has been reprinted virtually as received. It is for this reason that all of the information is not expressed in the same units. For example the fuel consumption of some engines is expressed in pounds per horsepower per hour, while in other cases it is expressed in gallons per hour, at cruising speed.

The ignition timing is given in degrees of crankshaft rotation before top dead center. Where two different timings are given, the letter "L" stands for the left hand and the letter "R" for the right hand magneto or distributor. In the case of the Allison engine, "E" stands for the distributor which feeds the spark plugs which are located on the exhaust side of the cylinders and likewise "I" indicates the intake side. The ignition timing for the Continental A-50 engines having only single ignition is 28° B.T.C.

The intake and exhaust valve clearances given are the "cold" or checking clearances. The timing clearances should be obtained from the specification tag attached to the engine or from the engine manual.

The spark plugs recommended are not to be considered as the only type approved for the engine. Many manufacturers recommend several types of plugs for each engine model, the best being determined by performance.

The weights given are for the engine dry (less liquid) and less optional equipment.

The following engine manufacturers are represented here:

Aeronautical Corporation of America (Aeronca), Cincinnati, Ohio.
Allison Engineering Company, Indianapolis, Indiana.
Continental Motors Corporation, Aircraft Engine Div., Detroit, Mich.
Engineering & Research Corp., (Erco), Riverdale, Maryland.
Jacobs Aircraft Engine Co., Pottstown, Pa.
Kinner Airplane & Motor Corp., Glendale, California.
Lenape Aircraft & Motors Corp., Matawan, N.J.
Aviation Manufacturing Corp., Lycoming Div., Williamsport, Pa.
Menasco Mfg. Co,, Los Angeles, Cal.
The Pratt & Whitney Aircraft Co., E. Hartford, Conn.
Ranger Engineering Corp., Farmingdale, N.Y.
Warner Aircraft Corp., Detroit, Mich.
Wright Aeronautical Corp., Patterson, N.J.

Although every effort has been made to insure the accuracy of the information herein, the authors cannot be responsible for errors or changes which may occur.

ENGINE SPECIFICATIONS

Engine	Model	Type	Cooling	Number of Cylinders	Rated B.H.P. (Sea Level)	Rated R.P.M. (Take-off)	Engine Weight
AERONCA	E-113-CBD	Hor. Opposed	Air	2	45	2300	125.5#
"	E-113-C	Hor. Opposed	Air	2	40	2300	121#
ALLISON	V-1710-C6	Upright Vee	Liquid	12	1000	2600	1280
CONTINENTAL	A-40 S.2,3,4,5	Hor. Opposed	Air	4	40	2575	144±
"	A-50 Ser. 1&3	Hor. Opposed	Air	4	50	1900	158±
"	A-50 Ser. 4&5	Hor. Opposed	Air	4	50	1900	160±
"	A-65 Ser. 1&3	Hor. Opposed	Air	4	65	2300	160
"	W-670 K	Radial	Air	7	225	2175	450
"	W-670 M	Radial	Air	7	240	2200	450
"	R-670 Std.	Radial	Air	7	210	2000	425
"	R-670 A,C,E &G	Radial	Air	7	210	2000	425
"	R-670 B,D,F &H	Radial	Air	7	225	2000	425
ERCO	1L-116	Inv. In-line	Air	4	65	3500	158
JACOBS	L-4 M,MB,MA	Radial	Air	7	225	2000	480
"	L-5 M,MB,MA	Radial	Air	7	285	2000	510
"	L-6 M,MB,MA	Radial	Air	7	330	2200	535
KEN-ROYCE	5-E	Radial	Air	5	70	1950	245
"	5-F	Radial	Air	5	90	2250	226
"	7-F	Radial	Air	7	120	2225	285
KINNER	K-5	Radial	Air	5	100	1810	275
"	B-5	Radial	Air	5	125	1925	295
"	R-5	Radial	Air	5	160	1850	321
"	C-5	Radial	Air	5	210	1900	420
"	C-7	Radial	Air	7	300	1800	630
"	SC-7	Radial	Air	7	350	1900	650
LENAPE	LM-3	Radial	Air	3	50	2200	138
"	LM-5	Radial	Air	5	90	2250	190
LYCOMING	O-145-C1	Hor. Opposed	Air	4	75	3100	155
"	O-145-C2	Hor. Opposed	Air	4	75	3100	165.5
"	O-145-C3	Hor. Opposed	Air	4	75	3100	167.5
"	O-145-A1	Hor. Opposed	Air	4	50	2300	152
"	O-145-A2	Hor. Opposed	Air	4	55	2300	162
"	O-145-A3	Hor. Opposed	Air	4	55	2300	164

ENGINE SPECIFICATIONS (Cont'd.)

Engine	Model	Type	Cooling	Number of Cylinders	Rated B.H.P. (Sea Level)	Rated R.P.M. (Take-off)	Engine Weight
LYCOMING	R-680-E1	Radial	Air	9	290	2300	514#
"	R-680-E2	Radial	Air	9	280	2300	514
"	R-680-E3	Radial	Air	9	300	2300	514
"	R-680-D5	Radial	Air	9	260	2300	505
"	R-680-D6	Radial	Air	9	245	2300	505
"	R-680-D4C	Radial	Air	9	225	2100	492
"	R-530-D1	Radial	Air	7	220	2300	430
"	R-530-D2	Radial	Air	7	210	2300	430
MENASCO	C4	Inv. In-Line	Air	4	125	....	300
"	C4S	Inv. In-Line	Air	4	150	2600	320
"	C6S-4	Inv. In-Line	Air	6	260	2300	550
"	U-520	Inv. Dual	Air	12	520	2300	1390
PRATT & WHITNEY	Wasp Jr. SB	Radial	Air	9	450	2300	645
"	Wasp SIHI-G	Radial	Air	9	600	2250	930
"	Hornet SIE2-G	Radial	Air	9	875	2300	1070
"	Tw.Wasp Jr. SB4-G	Radial Twin	Air	14	825	2625	1120
"	Tw.Wasp SIC3-G	Radial Twin	Air	14	1200	2700	1413
RANGER	SGU-770B-6	Inverted Vee	Air	12	500	2950	640
"	V-770B-4	Inverted Vee	Air	12	310	2400	565
"	6410 B-2	Inv. In-Line	Air	6	165	2450	345
WARNER	Super Scarab 40	Radial	Air	7	145	2050	303
"	Scarab 40	Radial	Air	7	125	2050	285
"	Scarab Jr. 40	Radial	Air	5	90	2025	230
WRIGHT	R-760-F (Wh.)	Radial	Air	7	325	2300	635
"	R-975-F (Wh.)	Radial	Air	9	425	2300	733
"	GR-1820-G102A	Radial	Air	9	900	2300	1260
"	GR-1820-G105A	Radial	Air	9	900	2300	1272
"	GR-1820-G2	Radial	Air	9	820	2100	1198
"	GR-1820-F52	Radial	Air	9	730	2100	1095

ENGINE SPECIFICATIONS (Cont'd.)

Engine	Model	Bore	Stroke	Piston Dis-placement	Compression Ratio	Impeller Ratio	Propeller Ratio	Fuel Consumption
AERONCA	E-113-CBD	4-1/4	4"	113.5 Cu.In.	5.4:1	...	1:1	.5#/hp/hr.
"	E-113-C	4-1/4	4	113.5	5.4:1	...	1:1	.5#/hp/hr.
ALLISON	V-1710-C6	5.5	6.0	1710	6:1	6.75:1	2:1	.58#/hp/hr.
CONTINENTAL	A-40 S.2,3,4,5	3-1/8	3-3/4	115	5.25:1	...	1:1	2.8 Gals./hr.
"	A-50 Ser. 1&3	3-7/8	3-5/8	171	5.4:1	...	1:1	2.75 Gal./hr.
"	A-50 Ser. 4&5	3-7/8	3-5/8	171	5.4:1	...	1:1	2.75 Gal./hr.
"	A-65 Ser. 1&3	3-7/8	3-5/8	171	6.3:1	...	1:1	4.5 Gal./hr.
"	W-670 K	5-1/8	4-5/8	668	5.4:1	...	1:1	15-20Gal./hr.
"	W-670 M	5-1/8	4-5/8	668	6.1:1	...	1:1	15-20Gal./hr.
"	R-670 Std.	5-1/8	4-5/8	668	5.2:1	...	1:1	15-20Gal./hr.
"	R-670 A,C,E &G	5-1/8	4-5/8	668	5.4:1	...	1:1	15-20Gal./hr.
"	R-670 B,D,F &H	5-1/8	4-5/8	668	6.1:1	...	1:1	15-20Gal./hr.
ERCO	1L-116	3.25	3.5	116.13	5.75:1	...	1:1	.5#/hp/hr.
JACOBS	L-4 M,MB,MA	5.25	5	757	5.375:1	...	1:1	.5#/hp/hr.
"	L-5 M,MB,MA	5.5	5	831	6:1	...	1:1	.53#/hp/hr.
"	L-6 M,MB,MA	5.5	5.5	914	6:1	...	1:1	.45#/hp/hr.
KEN-ROYCE	5-E	4.125	3.75	250.5	5.55:1	...	1:1	.6# /hp/hr.
"	5-F	4.25	3.75	266	6:1	...	1:1	.55#/hp/hr.
"	7-F	4.25	3.75	372	6:1	...	1:1	.57#/hp/hr.
KINNER	K-5	4-1/4	5-1/4	372	5:1	...	1:1	7 Gal./hr.
"	B-5	4-5/8	5-1/4	441	5.25:1	...	1:1	8 Gal./hr.
"	R-5	5	5-1/2	540	5.5:1	...	1:1	10 Gal./hr.
"	C-5	5-5/8	5-3/4	715	5.2:1	...	1:1	15 Gal./hr.
"	C-7	5-5/8	6	1044	5.25:1	...	1:1	21 Gal./hr.
"	SC-7	5-5/8	6	1044	5.5:1	9.7:1	1:1	21 Gal./hr.
LENAPE	LM-3	4-1/8	4	167	5:1	...	1:1	3 Gal./hr.
"	LM-5	4-1/8	4	275	5:1	...	1:1	6 Gal./hr.
LYCOMING	O-145-C1	3.625	3.5	144.5	6.5:1	...	1:1	.5#/hp/hr.
"	O-145-C2	3.625	3.5	144.5	6.5:1	...	1:1	.5#/hp/hr.
"	O-145-C3	3.625	3.5	144.5	6.5:1	...	1:1	.5#/hp/hr.
"	O-145-A1	3.625	3.5	144.5	5.65:1	...	1:1	.55#/hp/hr.
"	O-145-A2	3.625	3.5	144.5	5.65:1	...	1:1	.55#/hp/hr.
"	O-145-A3	3.625	3.5	144.5	5.65:1	...	1:1	.55#/hp/hr.

ENGINE SPECIFICATIONS (Cont'd.)

Engine	Model	Bore	Stroke	Piston Displacement	Compression Ratio	Impeller Ratio	Propeller Ratio	Fuel Consumption
LYCOMING	R-680-E1	4.625	4.5	680.4	6.2:1	1:1	1:1	.5#/hp/hr.
"	R-680-E2	4.625	4.5	680.4	5.5:1	1:1	1:1	.5#/hp/hr.
"	R-680-E3	4.625	4.5	680.4	7.0:1	1:1	1:1	.5#/hp/hr.
"	R-680-D5	4.625	4.5	680.4	6.5:1	1:1	1:1	.52#/hp/hr.
"	R-680-D6	4.625	4.5	680.4	5.5:1	1:1	1:1	.52#/hp/hr.
"	R-680-D4C	4.625	4.5	680.4	5.5:1	1:1	1:1	.52#/hp/hr.
"	R-530-D1	4.625	4.5	529.2	6.5:1	1:1	1:1	.52#/hp/hr.
"	R-530-D2	4.625	4.5	529.2	5.5:1	1:1	1:1	.52#/hp/hr.
MENASCO	C4	4.750	5.125	363	5.5:1	...	1:1	.5#/hp/hr.
"	C4S	4.750	5.125	363	5.5:1	9.6:1	1:1	.55#/hp/hr.
"	C6S-4	4.750	5.125	544.9	5.5:1	10.9:1	1:1	.55#/hp/hr.
"	U-520	4.750	5.125	1089.8	5.5:1	10.9:1	1.28:1	.55#/hp/hr.
PRATT &	Wasp Jr. SB	5.1875	5.1875	985	6:1	10:1	1:1	.465#/hp/hr.
WHITNEY	Wasp SIHI-G	5.75	5.75	1340	6:1	12:1	.666:1	.475#/hp/hr.
"	Hornet SIE2-G	6.125	6.375	1690	6.5:1	10:1	.666:1	.465#/hp/hr.
"	Tw.WaspJr. SB4-G	5.1875	5.1875	1535	6.75:1	11:1	.750:1	.465#/hp/hr.
"	Tw.Wasp SIC3-G	5.5	5.5	1830	6.7:1	7.15:1	.666:1	.470#/hp/hr.
RANGER	SGU-770B-6	4	5.125	773	6:1	8.84:1	3:2	.52#/hp/hr.
"	V-770B-4	4	5.125	773	6.5:1	...	1:1	.5#/hp/hr.
"	6410 B-2	4.125	5.125	411	6.5:1	...	1:1	.5#/hp/hr.
WARNER	Super Scarab 40	4-5/8	4-1/4	499	5.2:1	...	1:1	.53#/hp/hr.
"	Scarab 40	4-1/4	4-1/4	422	5.2:1	...	1:1	.53#/hp/hr.
"	Scarab Jr. 40	4-1/4	4-1/4	301	5.2:1	...	1:1	.53#/hp/hr.
WRIGHT	R-760-F (Wh.)	5	5.5	760	6.3:1	...	1:1	.48#/hp/hr.
"	R-975-F (Wh.)	5	5.5	975	6.3:1	10.15:1	1:1	.48#/hp/hr.
"	GR-1820-G102A	6.125	6.875	1823	6.3:1	7:1	16:11	.46#/hp/hr.
"	GR-1820-G105A	6.125	6.875	1823	6.3:1	10:1	16:11	.46#/hp/hr.
"	GR-1820-G2	6.125	6.875	1823	6.45:1	7:1	16:11	.44#/hp/hr.
"	GR-1820-F52	6.125	6.875	1823	6.4:1	7:1	16:11	.45#/hp/hr.

E N G I N E   S P E C I F I C A T I O N S (Cont'd.)

Engine	Model	Ignition	Type	Make	Ignition Timing B.T.C.	Intake Opens B.T.C.	Intake Closes A.B.C.	Exhaust Opens B.B.C.	Exhaust Closes A.T.C.
AERONCA	E-113-CBD	Dual	Magneto	Bosch FF2AL	35°	5°	55°	62°	12°
"	E-113-C	Single	Magneto	Bosch FF2AR	36°	5°	55°	55°	5°
ALLISON	V-1710-C6	Dual	Mag.&Dis.	Scintilla	E-38°,I-32°	44°	58°	76°	26°
CONTINENTAL	A-40 S.2,3,4,5	Either	Magneto	Scintilla	22°	10°	55°	55°	10°
"	A-50 Ser. 1&3	Either	Magneto	Scintilla	L28°,R25°	10°	35°	45°	15°
"	A-50 Ser. 4&5	Either	Magneto	Scintilla	L28°,R25°	10°	50°	50°	15°
"	A-65 Ser. 1&3	Either	Magneto	Scintilla	30°	10°	50°	50°	15°
"	W-670 K	Dual	Magneto	S.MN7-DF	L32°,R29°	A.T.C.4°	0°	49°	0°
"	W-670 M	Dual	Magneto	S.MN7-DF	L32°,R29°	A.T.C.4°	0°	49°	0°
"	R-670 Std.	Dual	Magneto	S.MN7-DF	L32°,R29°	8°-*8°	21°-*45°	63°-*55°	20°-*8°
"	R-670 A,C,E&G	Dual	Magneto	S.MN7-DF	L32°,R29°	8°-*8°	21°-*45°	63°-*55°	20°-*8°
"	R-670 B,D,F&H	Dual	Magneto	S.MN7-DF	L32°,R29°	8°-*8°	21°-*45°	63°-*55°	20°-*8°
ERCO	1L-116	Dual	Magneto	SF-4L	30°	15°	65°	65°	25°
JACOBS	L-4 M,MB,MA	Optional	Either	Scin.or Bat.	30°	12°	55°	55°	10°
"	L-5 M,MB,MA	Optional	Either	Scin.or Bat.	30°	12°	55°	55°	10°
"	L-6 M,MB,MA	Optional	Either	Scin.or Bat.	30°	18°	65°	58°	16°
KEN-ROYCE	5-E	Dual	Magneto	Bendix SB-5	25°	0°	60°	60°	0°
"	5-F	Dual	Magneto	Bendix SB-5	25°	0°	60°	60°	0°
"	7-F	Dual	Magneto	Scin.MN-7D	25°	0°	60°	60°	0°
KINNER	K-5	Dual	Magneto	Scintilla	R25°,L27°	25°	82°	71°	49°
"	B-5	Dual	Magneto	Scintilla	R25°,L27°	25°-**23	82-**94	65-**66°	42-**50°
"	R-5	Dual	Magneto	Scintilla	R25°,L27°	32°	100°	73°	54°
"	C-5	Dual	Magneto	Scintilla	R25°,L27°	32°	93°	79°	47°
"	C-7	Dual	Magneto	Scintilla	R25°,L27°	48°	94°	95°	51°
"	SC-7	Dual	Magneto	Scintilla	R25°,L27°	-	-	-	-
LENAPE	LM-3	Dual	Magneto	Ed.-Split.	28°	3°	52°	45°	10°
"	LM-5	Dual	Magneto	Ed.-Split.	30°	3°	52°	45°	10°
LYCOMING	O-145-C1	Single	Magneto	Scin. SF-4L	28°	20°	65°	65°	20°
"	O-145-C2	Dual	Magneto	Scin. SF-4L	25°	20°	65°	65°	20°
"	O-145-C3	Dual	Magneto	Scin. SF-4L	25°	20°	65°	65°	20°
"	O-145-A1	Single	Magneto	Scin. SF-4L	28°	10°	60°	60°	10°
"	O-145-A2	Dual	Magneto	Scin. SF-4L	25°	10°	60°	60°	10°
"	O-145-A3	Dual	Magneto	Scin. SF-4L	25°	10°	60°	60°	10°

*For engines using B-5046 cam **For rear exhaust engines

ENGINE SPECIFICATIONS (Cont'd.)

Engine	Model	Ignition	Type	Make	Ignition Timing B.T.C.	Intake Opens B.T.C.	Intake Closes A.B.C.	Exhaust Opens B.B.C.	Exhaust Closes A.T.C.
LYCOMING	R-680-E1	Dual	Magneto	Scin.-A2	L34°, R30°	40°	50°	65°	25°
"	R-680-E2	Dual	Magneto	Scin.-A2	L34°, R30°	40°	50°	65°	25°
"	R-680-E3	Dual	Magneto	Scin.-A2	L34°, R30°	40°	50°	65°	25°
"	R-680-D5	Dual	Magneto	Scin.-A2	L34°, R30°	15°	45°	60°	15°
"	R-680-D6	Dual	Magneto	Scin.-A2	L34°, R30°	15°	45°	60°	15°
"	R-680-D4C	Dual	Magneto	Scin.-A2	L34°, R30°	15°	45°	60°	15°
"	R-530-D1	Dual	Magneto	Scin.-A2	L34°, R30°	30°	60°	60°	30°
"	R-530-D2	Dual	Magneto	Scin.-A2	L34°, R30°	30°	60°	60°	30°
MENASCO	C4	Dual	Magneto	Bendix-Scin.	L30°, R35°	17°	77°	67°	27°
"	C4S	Dual	Magneto	Bendix-Scin.	L30°, R35°	17°	77°	67°	27°
"	C6S-4	Dual	Magneto	Bendix-Scin.	30°	10°	62°	52°	20°
"	U-520	Dual	Magneto	Bendix-Scin.	25°	15°	65°	60°	20°
PRATT & WHITNEY	Wasp Jr. SB	Dual	Magneto	Scintilla	25°	26°	76°	71°	31°
"	Wasp SIHI-G	Dual	Magneto	Scintilla	25°	26°	76°	71°	31°
"	Hornet SIE2-G	Dual	Magneto	Scintilla	25°	20°	77°	76°	21°
"	Tw.Wasp Jr.SB4-G	Dual	Magneto	Scintilla	25°	20°	76°	76°	20°
"	Tw.Wasp SIC3-G	Dual	Magneto	Scintilla	25°	20°	76°	76°	20°
RANGER	SGU-770B-6	Dual	Magneto	Ranger	25°	15°	65°	70°	30°
"	V-770B-4	Dual	Magneto	Ranger	30°	3°	51°	55°	20°
"	6410 B-2	Dual	Magneto	Ranger	30°	3°	51°	55°	20°
WARNER	Super Scarab40	Dual	Either	Scin.or Bat.	M32°, B15°	10°	60°	60°	10°
"	Scarab 40	Dual	Either	Scin.or Bat.	M32°, B15°	10°	60°	60°	10°
"	Scarab Jr. 40	Dual	Either	Scin.or Bat.	M32°, B15°	10°	60°	60°	10°
WRIGHT	R-760-F (Wh.)	Dual	Magneto	Scintilla	25°	10°	60°	75°	30°
"	R-975-F (Wh.)	Dual	Magneto	Scintilla	25°	10°	60°	75°	30°
"	GR-1820-G102A	Dual	Magneto	Scintilla	F20°, R15°	15°	44°	74°	25°
"	GR-1820-G105A	Dual	Magneto	Scintilla	F20°, R15°	15°	..	..	25°
"	GR-1820-G2	Dual	Magneto	Scintilla	F23°, R18°	15°	44°	74°	25°
"	GR-1820-F52	Dual	Magneto	Scintilla	23°	15°	44°	74°	25°

ENGINE SPECIFICATIONS (Cont'd.)

Engine	Model	Intake Valve Clearance	Exhaust Valve Clearance	Grade of Oil Summer (SAE)	Grade of Oil Winter (SAE)	Oil Pressure (Lbs. per sq.in.)	Oil Temperature	Spark Plugs Recommended
ERONCA	E-113-CBD	.005"	.005"	50-60	30-40	55	140°F.	BG 4B1
"	E-113-C	.005"	.005"	50-60	30-40	55	140°F.	Champion M3
LLISON	V-1710-C6	.010	.020	120*	100*	60-70	180	BG 321S
ONTINENTAL	A-40 X.2,3,4,5	.025	.020	20	20	30-40	120	Champion M31
"	A-50 Ser. 1&3	Automatic	Hydraulic	80	60	30	120 - 170	Cham.M31,M4
"	A-50 Ser. 4&5	Automatic	Hydraulic	80	60	30	120 - 170	Cham.M31,M4
"	A-65 Ser. 1&3	Automatic	Hydraulic	80	60	30-35	120 - 170	Cham.M31,M4
"	W-670 K	.010	.010	120	100	60-80	120 - 180	BG 4-B2
"	W-670 M	.010	.010	120	100	60-80	120 - 180	Cham. M31
"	R-670 Std.	.010	.010	120	100	50-80	120 - 180	Optional
"	R-670 A,C,E&G	.010	.010	120	100	50-80	120 - 180	Optional
"	R-670 B,D,F&H	.010	.010	120	100	50-80	120 - 180	Optional
RCO	1L-116	.010-.012	.010-.012	60-70	30-40	45	180	Cham. J-8
ACOBS	L-4 M,MB,MA	.008	.008	100*	80*	60-90	140 - 170	BG 4B2
"	L-5 M,MB,MA	.008	.008	100*	80*	60-90	140 - 170	BG 4B2
"	L-6 M,MB,MA	.008	.008	100*	80*	60-90	140	BG 4B2
EN-ROYCE	5-E	.015	.015	50	40	55	100 - 180	Champion 13
"	5-F	.010	.010	50	40	55	100 - 180	Champion 13
"	7-F	.010	.010	50	40	55	100 - 180	Champion 13
NNER	K-5	.020	.012	120	77	80-100	120 - 180	BG 4B2
"	B-5	.020	.020	120	77	80-100	120 - 180	BG 4B2
"	R-5	.008	.012	120	77	80-100	120 - 180	BG 4B2
"	C-5	.010	.010	120	77	80-100	120 - 180	BG 4B2
"	C-7	.010	.010	120	77	50-70	120 - 180	BG 4B2
"	SC-7	.010	.010	120	77	50-70	120 - 180	BG 4B2
NAPE	LM-3	.020	.020	100**	80**	75-90	100 - 120	Ed. Split.H82
"	LM-5	.020	.020	100**	80**	75-90	100 - 120	Ed. Split.
COMING	O-145-C1	.015	.015	40	30	70-80	220	Champion M31
"	O-145-C2	.015	.015	40	30	70-80	220	Champion M31
"	O-145-C3	.015	.015	40	30	70-80	220	Champion M31
"	O-145-A1	.015	.015	30	20	30-50	220	Champion M31
"	O-145-A2	.015	.015	30	20	30-50	220	Champion M31
"	O-145-A3	.015	.015	30	20	30-50	220	Champion M31

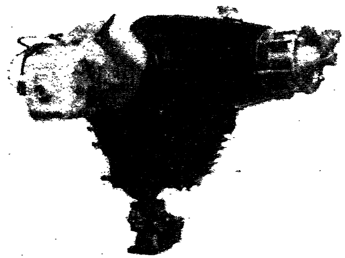
Saybolt **Aero Grade

ENGINE SPECIFICATIONS (Cont'd.)

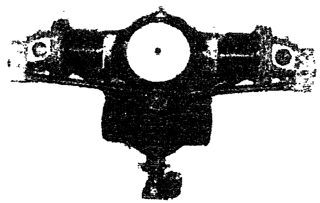
Engine	Model	Intake Valve Clearance	Exhaust Valve Clearance	Grade of Oil Summer (SAE)	Grade of Oil Winter (SAE)	Oil Pressure (Lbs. per sq.in.)	Oil Temperature	Spark Plugs Recommended
LYCOMING	R-680-E1	.015"	.015"	120	98	50-75	185°F.	BG-3B2
"	R-680-E2	.015"	.015"	120	98	50-75	185°F.	BG-4B2
"	R-680-E3	.015	.015	120	98	50-75	185	BG-4B2
"	R-680-D5	.015	.015	120	98	50-75	185	Bendix 7A
"	R-680-D6	.015	.015	120	98	50-75	185	Champ. M31
"	R-680-D4C	.015	.015	120	98	50-75	185	BG-4B2S
"	R-530-D1	.015	.015	120	98	50-75	185	BG-3B2
"	R-530-D2	.015	.015	120	98	50-75	185	BG-4B2
MENASCO	C4	.007	.007	120*	95*	40-50	200	BG 5B1
"	C4S	.007	.007	120*	95*	40-50	200	BG 5B1
"	C6S-4	.008	.008	120*	95*	50-60	200	BG 4B2
"	U-520	Zero Lash Tappet		120*	95*	50-60	200	BG 4B 2S
PRATT & WHITNEY	Wasp Jr. SB	.010	.010	120*	100*	70-90	185	
	Wasp SIHI-G	.010	.010	120*	100*	70-90	185	
"	Hornet SIE2-G	.010	.010	120*	100*	70-90	185	
"	Tw.Wasp Jr. SB4-G	.010	F.010-R.025	120*	100*	70-90	185	
"	Tw.Wasp SIC3-G	.010	.010	120*	100*	85-100	212	
RANGER	SGU-770B-6	.015	.030	120*	100*	50-70	140-170	344 S
"	V-770B-4	.015	.030	120*	100*	50-70	140-170	4B2, 4B2-S
"	6410 B-2	.015	.030	120*	100*	50-70	140-170	BG-5B-2S
WARNER	Super Scarab40	.010	.010	120*	100*	50-90	185	BG-5B-2
"	Scarab 40	.010	.010	120*	100*	50-90	185	AC Type N
"	Scarab Jr. 40	.010	.010	120*	100*	50-90	185	AC Type N
WRIGHT	R-760-F (Wh.)	.010	.010	120	120	60-80	140	BG-4B-2S
"	R-975-F (Wh.)	.010	.010	120	120	60-80	140	BG-29B GS
"	GR-1820-G102A	.015	.015	120	120	50-65	165	BG-298 GS
"	GR-1820-G105A	.015	.015	120	120	50-65	165	BG-298 GS
"	GR-1820-G2	.015	.015	120	120	50-65	165	BG-298 GS
"	GR-1820-F52	.015	.015	120	120	50-65	165	BG-314-S

*Saybolt

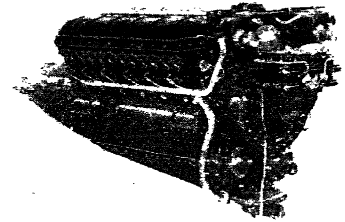
E N G I N E S



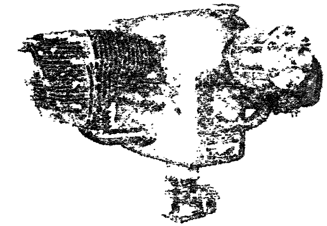
AERONCA E-113-C



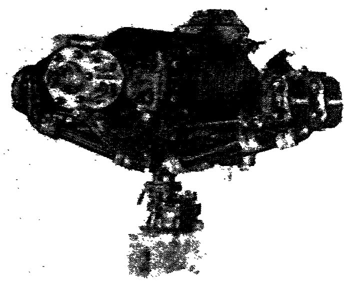
AERONCA E-113 C



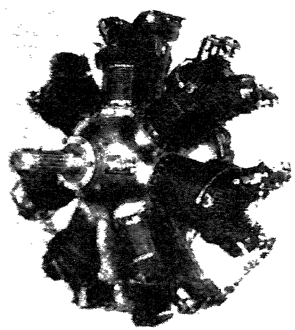
ALLISON V-1710-C6



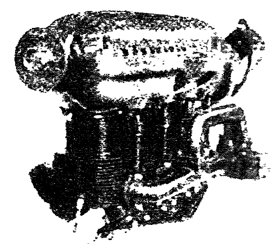
CONTINENTAL A-40



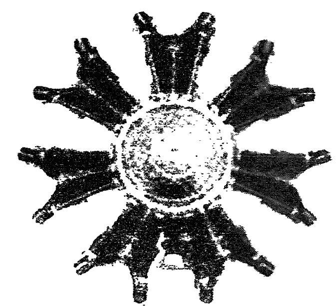
CONTINENTAL A-50



CONTINENTAL W-670



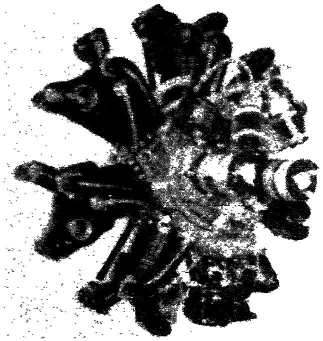
ERCO 1L-116



JACOBS L-4

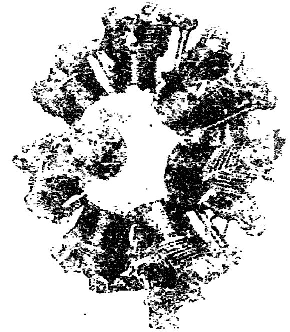
Illustrations by courtesy of Aero Digest

ENGINES



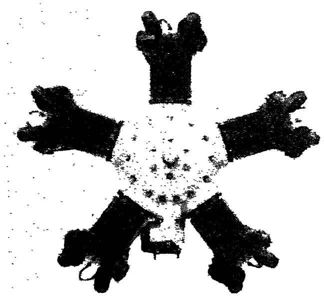
JACOBS L-5

KEN ROYCE 5-F

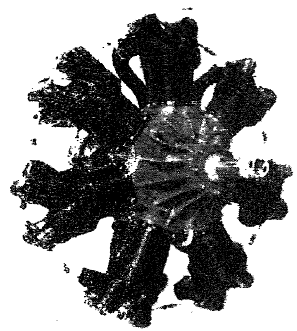


KEN ROYCE 7-DF

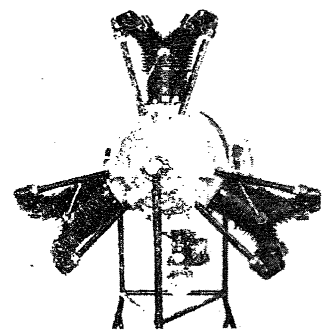
KINNER B-5



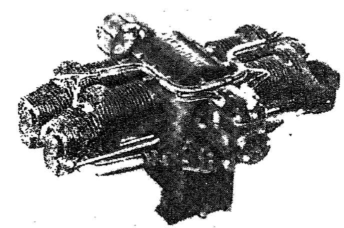
KINNER R-5



KINNER 5-C 7A



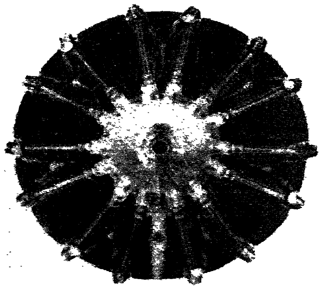
LENAPE LM-3



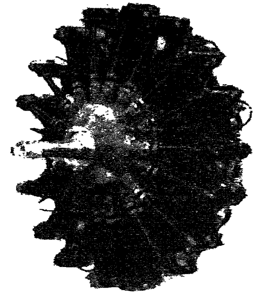
LYCOMING 0-145-A

Illustrations by courtesy of Aero Digest

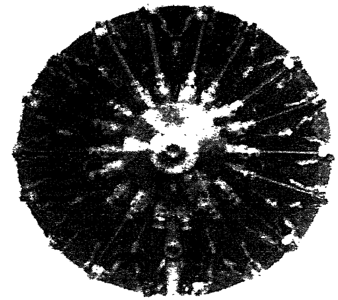
E N G I N E S



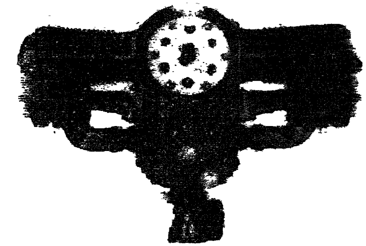
LYCOMING R-530-D



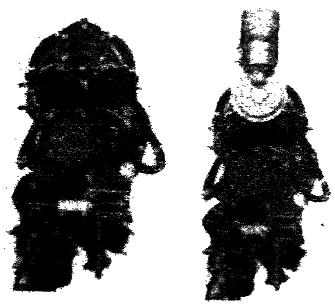
LYCOMING R-680-B4C



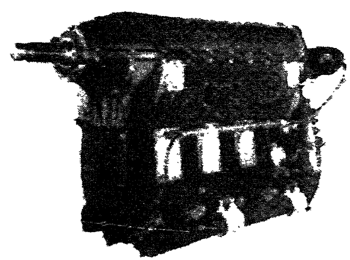
LYCOMING R-680-D



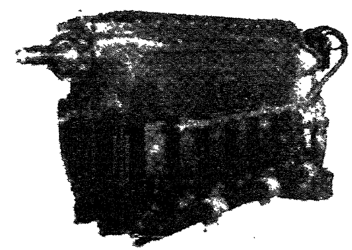
MENASCO M-50



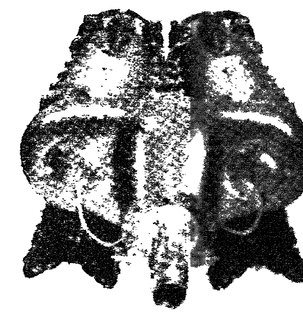
MENASCO PIRATE B



MENASCO PIRATE C

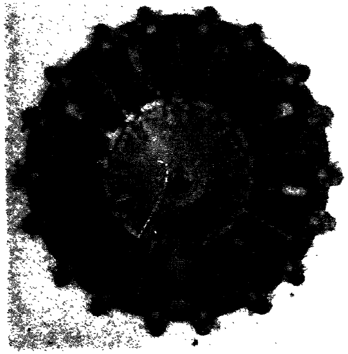


MENASCO BUCCANEER

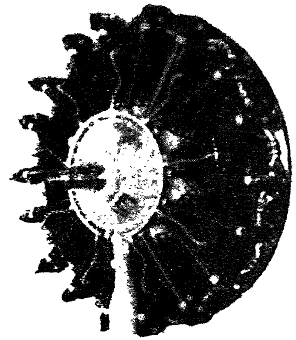


MENASCO UNITWIN

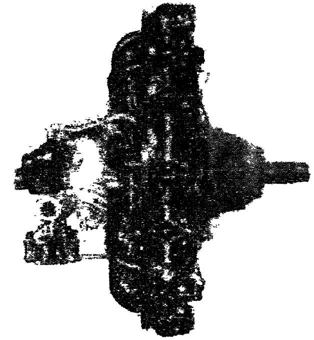
Illustrations by courtesy of Aero Digest



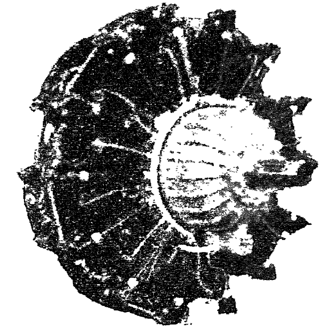
PRATT & WHITNEY WASP JR.



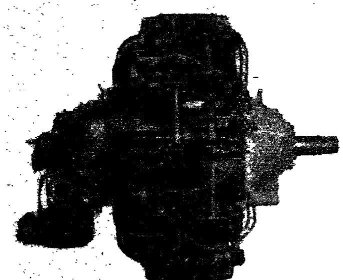
PRATT & WHITNEY WASP



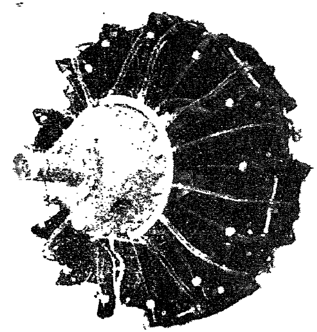
PRATT & WHITNEY HORNET



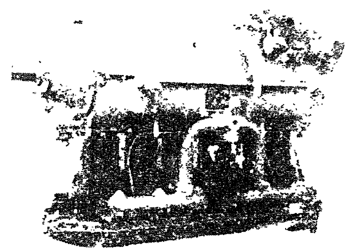
PRATT & WHITNEY TWIN WASP JR.



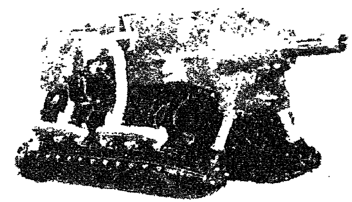
PRATT & WHITNEY TWIN WASP



PRATT & WHITNEY TWIN WASP



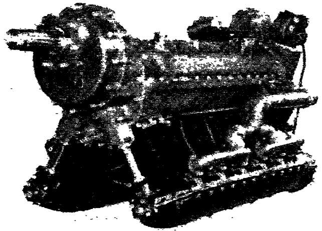
RANGER 6-410-B2

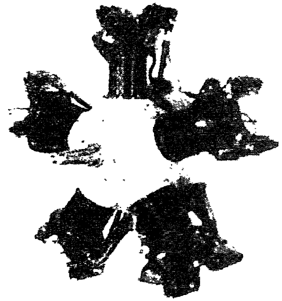


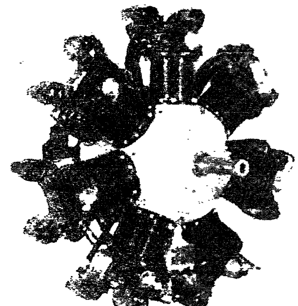
RANGER V-770-B4

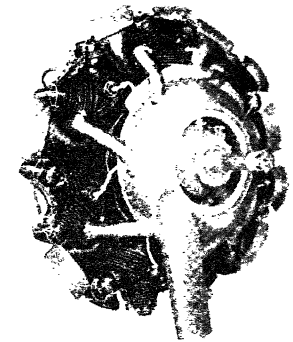
Illustrations by courtesy of Aero Digest

ENGINES

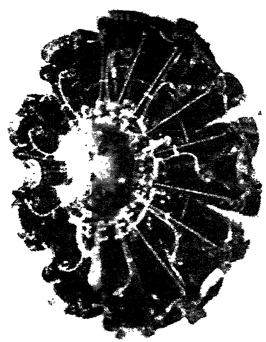

RANGER SGU-770-B

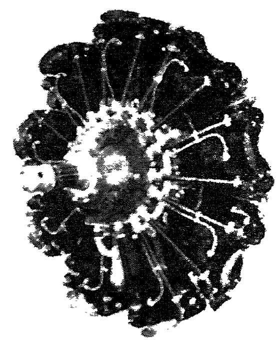

WARNER SCARAB JR.

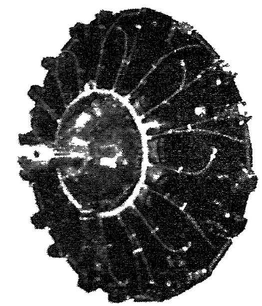

WARNER SCARAB


WRIGHT WHIRLWIND R-760


WRIGHT WHIRLWIND R-975


WRIGHT CYCLONE F-50


WRIGHT CYCLONE G


WRIGHT CYCLONE G-100

Illustrations by courtesy of Aero Digest

I N D E X